ECONOMIC GEOLOGY

VOL. XXXII AUGUST, 1937 No. 5

ROLE OF PHYSICAL CHEMISTRY IN STRATIGRAPHIC PROBLEMS.[1]

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ABSTRACT.

Stratigraphy is concerned mainly with the genesis and interpretation of stratified rocks, which include some of wide extent and of great scientific as well as economic interest that are largely of chemical rather than of detrital origin. Chemical agencies have been recognized to some extent in genetic studies of these rocks, but little work has been done approaching in maturity the type of study now given to the genesis of igneous rocks and of ores, in which physical chemistry plays so important a part.

A plea is presented to geologists with training in physical chemistry to interest themselves in stratigraphic problems that involve the use of this science. Examples cited are the phosphate beds and bedded cherts of the Phosphoria formation in Idaho and adjacent States and the potash-bearing Salado halite of the Permian basin in New Mexico and Texas. The interplay of ions in the solutions from which these formations were derived must have been controlled by such conditions as temperature, pressure, degree of concentration, and the like. Possibly laboratory study would enable us to reproduce these conditions and results and thus better interpret the geologic history of the times when these formations were built.

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[1] Published by permission of the Director, United States Geological Survey. Presented before the Society of Economic Geologists, New York, December, 1935.

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INTRODUCTION.

STRATIGRAPHIC units of chemical origin are relatively widespread in different parts of the world and occur on both a large and a small scale. Some of these units have been mapped and described, but their interpretation and geologic history are only imperfectly known because the chemical agencies responsible for their building have not been fully explored.

The economic importance of some of them, for example, the Lake Superior iron deposits, has led to extensive physico-chemical studies by many geologists, which have thrown much light on the geological conditions attending the genesis of these formations. Thus far, interest among economic geologists has centered largely on the origin of metallic ores. Physico-chemical methods of study in this field have been very fruitful and have led to rapid advances in knowledge of metallogenesis and to practical applications in ore finding.

The study of chemical deposits that are not directly related to metallic ores, or are only indirectly concerned with them, has on the whole fared rather badly in comparison. Outstanding examples, such as the classic studies of Van't Hoff on the Stassfurt salts and of Daly on the pre-Cambrian limestones, serve only to point the need and the benefits to be derived from such study.

The writer here calls attention to two sets of extensively distributed stratigraphic formations of chemical origin, with which

he has had personal experience, the interpretation of whose genesis and geologic history is dependent on physico-chemical methods of study. He wishes economic geologists to broaden their interests to include the genesis of such formations and in particular he invites them to study the two units mentioned, namely the Phosphoria formation of the northern Rocky Mountain region, which contains the great bulk of the nation's reserves of phosphates, and the Salado halite, which is the potash-bearing unit of the great Permian salt basin of the Southwest.

Phosphoria Formation.

The Phosphoria formation embraces two mappable units, each of which is in considerable part the product of chemical activity. The lower unit consists of a phosphate-bearing shale member and includes a number of phosphate beds that represent intermittent but very remarkable concentrations of tricalcium phosphate through considerable intervals of time. The upper or Rex chert member consists in large part of an equally extraordinary concentration of silica in the form of chert and related siliceous sediments. These two units are described briefly to emphasize their chemical origin and to show the need for their intensive study by modern physico-chemical methods.

Phosphate-Bearing Shale Member.

Character.—The phosphate shale-bearing member of the Phosphoria contains layers of oolitic phosphate ranging in thickness from a sixteenth of an inch or less to 4 or 5 inches and constituting beds that may range to 5 or even 10 feet in thickness. The total thickness of oolitic phosphate beds in the Georgetown Canyon area in southeastern Idaho is locally as much as 30 feet, and in southeastern Idaho generally it is probably not much less than 10 feet, whereas the thickness of the unit as a whole in that region is between 100 and 200 feet. The oolitic beds are accompanied by beds of sandstone, limestone, and shale most of which are phosphatic in some degree. Most of the beds also contain more or less organic matter that has a petroliferous odor in

freshly broken specimens and is locally sufficient to yield small amounts of oil upon distillation. The alternation of oolitic and clastic beds shows that the epochs of concentration of phosphates were intermittent and of unequal duration. The oolites themselves consist principally of the mineral collophanite, essentially tricalcium phosphate but containing other constituents, set in a matrix of the same material. In some places teeth and bits of shell may be recognized in the phosphate beds but in general fossils in these beds are scarce, except the brachiopod *Lingulidiscina*, which is locally abundant near the base. Locally, too, a highly fossiliferous bed, the "cap lime," is present and from it Girty has described a considerable fauna.[2]

The phosphate beds give clear evidence of the former presence of solutions rich in phosphate in the environment in which the oolites and some of the organic remains were deposited. Many of the oolites have concentric coatings of collophanite. Bits of shell have been phosphatized and teeth have been enlarged into phosphatic nodules. Carbonate and fluoride are also present in some of the phosphatic minerals and these ions must therefore have been present in the solutions just mentioned. Fluorite as a distinct mineral has been identified in Idaho and Montana phosphates.

The alternation of phosphate beds with limestone and terrigenous material indicates recurrent environmental conditions in which occurred concentrations now of calcium phosphate and again of calcium carbonate. The region extending northward from Rich County in northeastern Utah to the vicinity of Helena, Mont., seems to have had the richest concentrations of phosphates for the quality of the phosphate rock becomes poorer eastward and southeastward from this region and the percentage of limestone and of terrigenous material increases in those directions. Similarly the phosphate content of the beds decreases westward and southward. The phosphate deposits in British Columbia are also thinner and poorer. In general the phosphate shales become more calcareous eastward from southeastern Idaho and more

[2] Girty, G. H.: The fauna of the phosphate beds of the Park City formation in Idaho, Wyoming, and Utah. U. S. Geol. Surv. Bull. 436, 1910.

siliceous northward from that area. The recurrence of terrigenous material in the phosphate shales points either to diastrophic disturbances affecting the position of the shoreline, the depth of water, and the activities of waves and currents, or possibly to climatic changes affecting the rainfall and runoff and, therefore, the mechanical and chemical loads of streams tributary to the waters in which the phosphate beds were accumulating.

Question of Formation.—Whatever the boundaries of the so-called Phosphoria sea may have been we may consider its waters as a mixture of chemical solutions, which, along with ordinary sea water, supplied in relatively large amounts calcium, hydrofluoric and carbonic acids, together with lesser amounts of other constituents such as the oxides of iron, aluminum, and phosphorus. Different ions of organic origin were doubtless also present though these have not been specifically identified in the phosphate rock. The concentrations of these ions from these waters into deposits are no doubt due to several causes, chief among which are perhaps restricted circulation of the marine waters and cool or cold climatic conditions.

According to Graham [3] organic acids play a relatively greater part in the solution and redeposition of phosphates than carbonic acid. With little doubt some of these ions tended to retard or facilitate the chemical reactions which determined whether phosphate or carbonate should be deposited. The degree of alkalinity or acidity of the water was doubtless also a contributing factor to the final product. Fluorine may have acted as an exciting agent or trigger cause in promotion of phosphate deposition. Temperature and degree of concentration probably played important parts. Different authors have called attention to glaciation in Permian time and have argued that cool climate accompanying glaciation was perhaps a factor in phosphate deposition.

The writer has elsewhere [4] reviewed the literature and stated

[3] Graham, W. A. P.: Experiments in the origin of phosphate deposits. Econ. Geol., vol. 20, pp. 319–334, 1925.

[4] Mansfield, G. R.: Geography, geology, and mineral resources of part of southeastern Idaho. U. S. Geol. Surv. Prof. Paper 152, pp. 361–367, 1927. Some problems of the Rocky Mountain phosphate field. Econ. Geol., vol. 26, pp. 353–374, 1931.

his views on the origin of the western phosphates, and it is not necessary to repeat them here. In this paper it is intended merely to point out some of the many chemical factors involved in the solution of the problem and to emphasize the need of the application of physical chemistry to it if further progress is to be made. If the conditions of phosphate accumulation can be thus established with any confidence it should be possible by working backward to obtain more accurate ideas of the geologic history of Permian time in the northern Rocky Mountain area. Mineralogical studies are also greatly needed. As in the studies of potash minerals mentioned further on, these might yield an order of succession or replacement data that would be most helpful in geologic interpretations.

Rex Chert Member.

Character.—The change from the lower to the upper member of the Phosphoria formation in the southeastern Idaho area is marked by an abrupt change in constituent rocks. Massive beds of chert and locally of limestone, which constitute the Rex chert member, overlie the shaly and phosphatic beds of the lower member. Topographically the Rex chert forms hills or ridges or even massive stone walls where upturned beds course for miles across country. The lower member on the other hand forms sags in the ridges and depressions between the chert beds on one side and underlying limestones on the other. Although organic matter and its dark color persist in the Rex in many places the phosphate does not, and in its place are thick and extensive accumulations of silica. The formation has undoubtedly suffered greatly from structural disturbances and erosion, but it still covers many hundreds if not thousands of square miles.

Origin.—The origin of chert in general has given rise to a long controversy that still persists. The writer has already expressed himself on the subject elsewhere [5] and will here merely reaffirm his view that the bedded cherts associated with the Permian phosphates in the Idaho area are original marine deposits chiefly of

[5] *Op. cit.*

chemical origin. A single bed of considerable extent and composed chiefly of siliceous sponge spicules has been recognized but this constitutes only a small part of the chert formation as a whole. In general the rock is composed of very fine grained crystalline silica. In the upper part throughout a considerable area enough shaly matter is included with the chert to make flinty shales that break into small, hard, and sharply angular fragments. Southward and eastward the chert grades to limestone, in places highly fossiliferous, and northward it grades into quartzite. Farther west extensive beds of volcanic tuff containing marine fossils of Permian age point to volcanic activity or volcanic products as possible sources for much of the silica. Volcanic ash has in fact been recognized at one locality in the chert.

Volcanic tuffs seem rather easily susceptible to loss of silica through solution. The silica so dissolved may be deposited nearby as chalcedony or opal or under certain conditions may perhaps be retained in solution and later deposited at places more remote from its source. If, as seems probable, the silica for the Permian chert beds of the Northern Rocky Mountain area was derived in considerable part from volcanic sources means must be found for retaining it in solution long enough to permit its transportation to the sites of deposition and there in turn conditions necessitating its precipitation or deposition must have been present. Possibly intermediate stages of deposition and re-solution may have intervened but of this no evidence has yet been recognized. The whole problem of transfer of silica from volcanic or other sources to final deposition possibly hundreds of miles away in bedded cherts is largely chemical.

Analogy to Lake Superior Iron Formations.—In many ways the problem of chert accumulation in the so-called Phosphoria sea of Permian time is analogous to that of the origin of the highly siliceous iron-bearing formations of the Lake Superior region. In both regions silica in relatively large amounts has been removed by solution from sources more or less remote from the areas where it is now found and has been redeposited in quantity by some modification or reversal of conditions in the solutions that originally dissolved and transported it.

Bearing of Experiments.—Experiments designed chiefly to explain the origin of the Lake Superior iron-bearing formations have been conducted by Harder,[6] Gruner,[7] Lovering,[8] and Moore and Maynard,[9] who cite other authors. Tarr[10] also has made significant contribution to the general problem of the bedded cherts. The results of these studies seem to indicate that silica in amounts less than 30 parts per million may be transported in cold natural waters but in greater amounts it may be precipitated by electrolytes such as those present in sea water. Tarr brings out the relative importance of organic ("protective") colloids in delaying or preventing coagulation of the silica and thus furthering its transportation.

Restricted Circulation a Factor.—Factors favorable for the concentration and deposition of the transported silica may perhaps be found in the idea previously advanced by the writer[11] with respect to the Phosporia sea. The circulation in the more central parts of this sea seems to have been poor. In its earlier history the marginal areas were apparently occupied by normal marine sediments of different kinds, but toward the middle increasingly abundant accumulations of phosphate were laid down and the importance of the normal type of marine sediments was correspondingly diminished. Similarly during the time interval represented by the Rex chert concentrations of bedded chert were thick and widespread in the more central areas of the sea but gave way to more normal types of marine sediments toward the margins. It would seem that restricted circulation of the waters of the Phosphoria sea permitted accumulation of colloidal silica in

[6] Harder, E. C.: Iron-depositing bacteria and their geologic relations. U. S. Geol. Surv. Prof. Paper 113, 1919.

[7] Gruner, J. W.: The origin of sedimentary iron formations: the Biwabik formation of the Mesabi Range. ECON. GEOL., vol. 17, pp. 407–460, 1922.

[8] Lovering, T. S.: The leaching of iron protores. Solution and precipitation of silica in cold water. ECON. GEOL., vol. 17, pp. 523–540, 1923.

[9] Moore, E. S., and Maynard, J. E.: Solution, transportation and precipitation of iron and silica. ECON. GEOL., vol. 24, pp. 272–303; 365–402; 506–527, 1929.

[10] Tarr, W. A.: The origin of chert and flint. Univ. Missouri Studies, vol. 1, no. 2, vi + 46 pp., 10 pls., April 1, 1926.

[11] Mansfield, G. R.: Some problems of the Rocky Mountain phosphate field. ECON. GEOL., vol. 26, pp. 353–374, 1931.

amounts sufficiently great to permit precipitation by the electrolytes of sea water in the central areas. This condition must have persisted through much, perhaps more than half, of the epoch represented by that sea. Organic matter, though present to some extent in the waters of Rex time, was much less than in that of the immediately preceding epoch in which the phosphate shales were laid down, for the Rex chert is not notably phosphatic.

Salado Halite.

Name and Character.—The name Salado halite has been given by Lang [12] to the upper division of the salt series that underlies the Rustler formation in the Pecos Valley area of New Mexico and Texas. He states:

> In 1923 the writer recognized that the salt section was divisible into two major units and orally introduced the terms "Upper" and "Lower" salt series, the basis for the separation at that time being that the "upper" part is shaly, pinkish, and on analysis generally shows more than 1 per cent. of K_2O, whereas the "lower" has a dull grayish appearance and on analysis yields less than 1 per cent. of K_2O. The upper salt series is dominantly composed of rock salt with massive anhydrite beds, red-beds, shaly sands, and prominent beds and lenses of polyhalite that are characteristic only of this formation. [The polyhalite beds are now known also to exist in massive beds of such extent and thickness as to raise this mineral to the status of a rock.] Also in the upper part of this upper series are to be found local concentrations of the chloride and sulphate salts of potassium, of which sylvite, carnallite, and langbeinite are the essential representatives and which are exposed in the potash mine shafts some 20 miles east of Carlsbad. Although this upper salt series underlies an area of more than 60,000 square miles, it has no definitely known outcrop, the nearest approach to an outcrop being in eastern Culberson County. Here weathering has so deeply altered the anhydrite to gypsum that if the disrupted anhydrites of the upper series were present they would be difficult to recognize. The name Salado halite is given to this upper salt series, from Salado Wash in northern Loving County, Texas. . . . The Salado halite has suffered pre-Rustler erosional truncation in Eddy County, New Mexico, and in Reeves, Culberson, and western Loving counties, Texas, and has also been affected in those areas where the more

[12] Lang, W. B.: Upper Permian formations of the Delaware Basins of Texas and New Mexico. Am. Assoc. Pet. Geols., vol. 19, pp. 262–270, 1935.

prominent reef masses accumulated. It extends in the Means well from the depth of 920 feet to 2,350 feet.

The lower salt series crops out in Eddy County, New Mexico, and Culberson County, Texas. It is the formation to which Richardson gave the name Castile gypsum as including all rocks between the Delaware Mountain and Rustler formation. Richardson was not then aware of what is now revealed in the well logs. As the outcropping gypsum is part of or represents the lower salt series and is only a surficial alteration by weathering of the main mass of anhydrite in subsurface, it seems fitting to apply to the lower salt series the name Castile anhydrite. The Castile anhydrite extends downward [in the Means well] from 2,350 to 4,990 feet, where it lies unconformably on the Delaware Mountain formation.

Core Tests.—The Salado halite is composed largely of halite and anhydrite with some clay. Special interest attaches to it because it contains beds of potash salts, which recur at intervals in it. Some of these are now being mined in Eddy County, New Mexico. Core drilling in these beds has been intermittently in progress in the Permian area east of the Pecos River since 1926 when the Government's program of core drilling began and the Snowden McSweeny Co. started their private core testing. In all 95 core tests, including 23 by the Government, have been drilled through the potash-bearing beds in the New Mexico area. Samples from most of these test wells have been studied in the laboratories of the Geological Survey and the results obtained from the Government core tests have been published by the Geological Survey of Texas.[13]

Mineralogical Conditions Recognized.—An earlier report including a mineralogical study by Schaller and Henderson[14] of core material from both public and private core tests has been published by the U. S. Geological Survey. These authors have done much to show how the different potash-bearing minerals have been formed. As an outstanding result their work shows clearly that many of the potash beds and the minerals of which

[13] Mansfield, G. R., and Lang, W. B.: The Texas-New Mexico potash deposits. Univ. Texas Bull. 3401, pp. 641–832, Dec., 1935.

[14] Schaller, W. T., and Henderson, E. P.: Mineralogy of drill cores from the potash field of New Mexico and Texas. U. S. Geol. Surv. Bull. 833, 1932.

they are composed have been formed by the replacement of earlier beds or groups of other minerals. Though there is reason to believe that some of the polyhalite beds at least may be of primary deposition the evidence is clear that many of them are secondary. Replacement as a mode of formation has been more clearly and widely shown in the formation of polyhalite than in some of the other potash minerals, but since this is in general the earliest formed of the group the probability is great that the others have been formed in similar manner. The excellent illustrations in the work cited show many stages in the process of replacement. In some specimens wisps and fibers of polyhalite in anhydrite are seen to have grown into larger masses. Similarly spherulites of polyhalite have grown in anhydrite and have coalesced to form lenses or beds of polyhalite. Polyhalite has formed as blebs in halite or as spherulites along cleavage planes in halite. The further growth of these bodies has separated masses of halite so that they in turn have become blebs of halite in polyhalite or have disappeared altogether leaving again beds of polyhalite .

A very striking case is presented where anhydrite finely banded with magnesite is subjected to replacement. Here the earliest change seems to have been the upward growth of gypsum from suitably placed beds or layers of magnesite. The gypsum crystals had developed the characteristic fish-tail twin form and attained lengths as great as five inches in some instances, though mostly they did not exceed one or two inches. However, only the form, not the substance, of the gypsum crystals was preserved. The forms or molds were filled with halite. Some of the pieces of core with these halite masses masquerading as gypsum crystals have a very striking appearance. Many of the cores show the gypsiform halite partly or wholly replaced with polyhalite. Complete sequences may be observed from clear halite to halite suffused pink with polyhalite and finally pure polyhalite. As in the instance cited of spherulites coalescing to form bands or beds so the polyhalite pseudomorphs after gypsum tend to form beds or masses of pure polyhalite. The work cited shows many details of such replacement as those just described.

The case of direct replacement of halite by sylvite is not so striking but nevertheless the evidence seems conclusive that sylvite is formed as a secondary mineral. Sylvite is derived largely from carnallite, a mineral formed directly from sea water. The case for replacement for some of the other potash minerals such as leonite and langbeinite has not been worked out so clearly, but the implications for their formation by replacement are also strong.

Bearing on Geologic History.—According to Van't Hoff's theories, the slow evaporation of seas would lead in general to the concomitant deposition of more than a single salt after the first stages. Thus, polyhalite, epsomite, leonite, and kainite might all deposit together. Afterwards the more hydrated minerals might be changed to less hydrated or anhydrous minerals, for example, at higher temperatures.

Considering the geologic history of the Salado halite, it may be noted that in general the lower part is composed largely of anhydrite, whereas above are considerable thicknesses of halite, alternating more or less with anhydrite, and with beds containing some or much polyhalite. H. I. Smith's [15] diagram and section of the potash beds in the productive area in New Mexico shows the arrangement of some of these beds. He states [16] that all the anhydrite beds above bed 40 are in some places replaced by polyhalite and that bed 24 is the only one that persistently contains as much as 50 per cent. of anhydrite. In the mined areas the sylvite-bearing portion of the section is relatively near the top but elsewhere in the field uneroded higher beds cover the potash beds more deeply. The cores show rather definite sequences of mineral deposition. According to Schaller and Henderson [17] "a typical sequence, repeated many times in the same core, begins with a layer of clay at the bottom, grading upward into anhydrite on which rests polyhalite. This sequence is followed by halite with a little polyhalite ('blebby salt') scattered all through it,

[15] Smith, H. I.: Potash development in southeastern New Mexico. Am. Inst. Min. and Met. Engrs. Cont. 52, 15 pp. (pp. 8–9), Feb., 1933.

[16] Same. Personal communication.

[17] *Op. cit.*, p. 8.

over which comes nearly pure halite." Many of these sequences do not include sylvite or langbeinite, but in the upper parts of the cores some sequences do contain them. The fact that these mineral sequences are repeated many times, especially as regards polyhalite, shows that there was no great uninterrupted epoch of desiccation in which the less soluble minerals were first deposited followed by the more soluble minerals. However, the sequences containing sylvite and its associates indicate that desiccation was on the whole farther advanced in that part of Salado time when these minerals were forming than at other times. The striking thing is the repetition of sequences, which shows that the salinity of the sea was affected by diastrophic or climatic changes, which from time to time permitted the waters to become less saline for considerable periods.

Though the succession of replacements described above argues strongly for the secondary origin of the potash minerals, it is possible that some, perhaps much, of the polyhalite may have been laid down as original chemical sediments. Cunningham [18] states that "the greater prevalence of polyhalite near the edge of the salt basin and in the vicinity of the pronounced structures in the underlying limestone instead of in the middle of the basin may be further evidence of the secondary formation of polyhalite. Calcium sulfate carried in solution by the fresh water streams entering a large body of salt water will tend to be precipitated near the point of entrance. As the concentration of potassium and magnesium sulfates in the brine increases, the anhydrite or gypsum previously deposited will tend to be dissolved and re-precipitated as polyhalite. The incoming calcium sulphate might well be dissolved and re-precipitated as polyhalite in its passage through the brine and be initially deposited as polyhalite. . . . Whatever the mode of formation, it appears quite evident that the proximity of the land masses which serve as a source of calcium sulfate might explain the prevalence of polyhalite in the 'shallower' portions of the basin." Cunningham's idea that the limestone in certain parts of the Permian area may have affected

[18] Cunningham, W. A.: The potassium sulfate mineral polyhalite in Texas. Univ. Texas Bull. 3401, vol. II, pp. 833–867, 1934.

the composition of the brine in those areas and hence the nature of the chemical sediments deposited is supported by the experience of Nolan,[19] who, in studying the brines of the Salt Lake Desert, found that the relative amounts of potassium and magnesium present depend upon the type of rock in the adjacent highland. The fact that some of the polyhalite-anhydrite beds extend over wide areas shows that such marginal modifications in the composition of the beds probably are rather local. However, Cunningham cites other evidences "which are not in full accord with the replacement theory" and lead him to the conclusion "the polyhalite of the Permian basin is of both primary and secondary origin."

It may be questioned if desiccation of the brines in the Permian Basin was ever complete during the period of saline deposition and if the potash-bearing minerals were ever actually formed under surface conditions. Ageton [20] has interpreted certain features of the potash beds, disclosed by mining operations in New Mexico, on the one hand as effects of erosion of salt beds exposed at the surface and on the other as bar- or beach-like accumulations, again implying the presence of potash salts at the surface. The evidence of replacement cited above makes such interpretations seem unlikely and the writer doubts if any of the potash minerals were actually formed at the surface of the salt body as crusts of a briny lake. Replacements might be expected to take place within the body of a spongy salt mass saturated with brine, such as that of Searles Lake, Calif., today, or in permeable beds in a salt body soaked with brine. Such changes might occur relatively near the surface under some conditions, but they might also take place in masses or beds that had become deeply buried by deposition of later sediments or by diastrophic agencies.

Comparison with the Deposit in Searles Lake.—A modern example of the way in which some potash-bearing salt masses have been formed in the past is furnished by Searles Lake, Calif.

[19] Nolan, T. B.: Potash brines in the Great Salt Lake Desert, Utah. U. S. Geol. Surv. Bull. 795, pp. 25–44, 1927.

[20] Ageton, R. V.: Salt occurrences in the potash mines of New Mexico. Am. Inst. Min. and Met. Engrs., Tech. Pub. 686, 1936.

Here a salt mass 10 or 12 square miles in extent and 70 to 75 feet thick in its main part forms a great sponge, which, though fairly close textured and under usual conditions dry at the surface, is in fact filled with brine downward from a depth of a few inches. The American Potash and Chemical Corporation manufactures from these brines potassium chloride, borax, and some other salts. Certain potash-bearing minerals, such as glaserite, have also been obtained from cores bored in the deposits by the company, but so far as known to the writer none of those minerals mentioned above in connection with the Permian Basin have been found in them. On the other hand boron compounds, abundant enough at Searles Lake to be manufactured into borax, are present only in the merest traces in the Permian Basin. The American Potash and Chemical Corporation maintains a research staff, the effectiveness of which is manifest in the way complex problems of chemical engineering have been mastered in producing pure chemicals from the brine. What is happening in nature's laboratory whose finished product is delivered at the company's pumps, is less well understood. The company makes borings and tests to assure itself of adequate supplies of brine. In addition to its chemical technological studies the company may have made equally thorough study of the geological and mineralogical processes involved in the development of the deposit of Searles Lake itself. If not, there would seem to be a fine chance for the company to employ some geologist with physico-chemical training to work with their staff either as a regular employee or as a representative of some cooperating agency acceptable to the company in the study of this fascinating problem.

Age of Salado Halite.—The age of the salt beds in the Permian Basin is regarded as Permian. It would be interesting to know if the formation of the potash-bearing beds had been completed at the end of that period. Secondary activity could continue in the salt and potash beds as long as solutions were present. Geologic evidence shows that much of the Permian area was buried by Mesozoic and later sediments. As these increased in thickness the salt beds were doubtless depressed and possibly invaded

by higher temperatures, while at the same time they were subjected to greater pressures by loading. As the beds were later raised and the overburden partly eroded conditions of temperature and pressure were no doubt reversed to some extent. If original brines were present in sufficient quantity to wet the salts during all this time there would seem to be no reason why deposition, resolution, and re-deposition in the same or other arrangement may not have taken place many times. In that event the actual potash minerals now disclosed in cores and mines may really be of relatively recent date, although the potash and other constituents were furnished in Permian time.

Possible Effects of Ground Water.—Another factor of possible importance is ground water of meteoric origin. In parts of New Mexico ground water occurs in some abundance in certain beds above the salt. In other places no ground water was encountered above or in the salt beds. Perhaps ground water may have been entirely sealed off from the salt beds and have played no part in the formation of the deposits now recognized. On the other hand it seems quite probable that ground water may have found access to some parts of the salt mass and have had some share in the chemistry of the deposits.

Water Squeezed from Salt Specimens.—Interest thus attaches to certain experiments performed by the Bureau of Mines [21] at the request of the Geological Survey to determine the relative size and strength of pillars to be left in mining potash on public leased lands. Compression experiments made as a part of this program developed the fact that at pressures of 1600 pounds or more water could be squeezed out of the salt specimens and that in at least one salt specimen its volume was a little over 1 per cent. of the volume of the specimen. The composition of the salts contained in this water was comparable to that of the salts in which it was contained. This water, which is apparently interstitial, may have been a relic of the ancient Permian brine trapped in the salt, or possibly ground water.

[21] Greenwald, H. P.: Third progress report, tests of compressive strength of potash salt from Carlsbad, New Mex., Dec. 1, 1933. Same, Fourth progress report, Sept. 11, 1934.

From the above outline it is clear that the Salado halite affords many alluring problems for the geologist trained in physical chemistry or for the geologist and the physical chemist in cooperation. Satisfactory solution of some of these problems will clarify many pages in the geologic history of the Permian that without such study must remain obscure.

ACKNOWLEDGMENT.

The writer gratefully acknowledges his indebtedness to Messrs. R. C. Wells, W. T. Schaller, H. I. Smith, and W. B. Lang who have read the manuscript and offered helpful criticisms.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
April 26, 1937.

ISOMETRIC BLOCK DIAGRAMS IN MINING GEOLOGY.[1]

W. D. JOHNSTON, JR., AND T. B. NOLAN.

ABSTRACT.

In the past five years members of the Geological Survey have gained experience in making isometric block diagrams of mines and mining districts as well as of surface features. This paper presents nothing new, but aims to assemble scattered information on a much neglected method of geological illustration. Plotting mine workings on isometric paper is the usual method but is extremely time-consuming. For most purposes the use of some form of isometric pantograph greatly lessens the labor of constructing the diagram. The devices of Dufour, Wentworth, Wilson, and Van der Hoop are described.

INTRODUCTION.

STRUCTURAL geology is handicapped by the difficulty of representing three-dimensional data by means of two-dimensional maps, plans, and sections. A geologic map on a topographic base with emplaced cross sections, as used in the structural section sheets of the Geologic Folios of the U. S. Geological Survey, gives much help in vizualizing the space relations of the geologic units mapped. Better aids to three-dimensional vizualization are provided by the serial sections used by many Alpine geologists or by the " egg crate " or " fence " diagrams such as those by Baker,[2] Dane, and Reeside, illustrating wide-range stratigraphic correlation; though both methods necessarily require the omission of essentially all data regarding areal distribution.

Geomorphologists have used block diagrams extensively as a

[1] Presented before the Society of Economic Geologists, New York Meeting, Feb. 17, 1937. Published by permission of the Director, U. S. Geological Survey.

[2] Baker, A. A., and Reeside, J. B., Jr.: Correlation of the Permian of southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado. Am. Assoc. Pet. Geol. Bull., vol. 13, fig. 9, p. 1438, 1929.

Baker, A. A., Dane, C. H., and Reeside, J. B., Jr.: Correlation of the Jurassic formations of parts of Utah, Arizona, New Mexico, and Colorado. U. S. Geol. Surv. Prof. Paper 183, pl. 10, 1936.

means of presenting geomorphologic data in three dimensions. Lobeck [3] has presented an extensive account of such diagrams. Although it was designed especially for geomorphologists, it should be consulted by anyone who desires to prepare three-dimensional diagrams.

Three-dimensional diagrams of various kinds have been used in mining geology for many years.[4]

Serial sections or plans drawn on glass are maintained at many mines and photographs of such models have been used as illustrative material in published reports, though they are commonly unsatisfactory. Similarly skeleton models of wire or of wooden strips have been constructed, especially for use in mining litigation and photographs of these have appeared in print. Commonly, however, three-dimensional diagrams prepared as illustrations of underground geology have taken the form of block diagrams of two general types—one in which the block is regarded as a transparent solid, with the ore shoots or other geologic features to be illustrated shown as opaque or translucent;[5] the other, isometric diagrams in which shelves and separated blocks are utilized to illustrate the geology shown by the mine workings. The "transparencies" or stereograms have rather limited application since relatively few geologic features can be shown and they also require considerable artistic facility in properly shading the opaque or translucent objects. Probably because of these two objections, the "cut out" isometric diagrams are more popular at present, and they form the chief subject of this paper. They are not a new development, however, as two by Drysdale [6] were

[3] Lobeck, A. K.: Block diagrams. John Wiley and Sons, New York, 1924.

[4] Sopwith, T.: Isometric projection of mine plans, 1832. Clayton, H. E.: Isometric mine plans, their applications, limitations, and methods of construction. Australasian Inst. of Mining Engineers, N. S., no. 34, pp. 9–18, 1919. Wilson, W. H.: Tri-dimensional projection of mine workings. Inst. Min. and Met. (London), Trans., vol. 43, pp. 545–591, 1934.

[5] Stereograms of this type are illustrated by B. S. Butler: Geology and ore deposits of the San Francisco and adjacent districts, Utah. U. S. Geol. Surv. Prof. Paper 80 (Fig. 12, p. 125 and Fig. 14, p. 130), 1913.

[6] Drysdale, C. W.: Geology of the Franklin mining camp. Can. Geol. Surv., Mem. 56, 1915. Drysdale, C. W.: Geology and ore deposits of Rossland, B. C. Can. Geol. Surv., Mem. 77, 1915.

published in 1915 in his reports on the Rossland and Franklin districts, British Columbia. The block diagram of Rossland shows most of the features found in present-day diagrams of this type. A recent example is provided by two diagrams to illustrate a report on the Tonopah district in Nevada.[7]

Our reason for presenting this paper, which contains nothing that is original with us, is that our colleagues have shown a keener interest in methods of constructing block diagrams of mines and mining camps than they ever have in those of our geological problems which we fondly believed to contain elements of originality.

THE CHOICE OF A PROJECTION.

In any block diagram that is drawn without perspective, points in space are referred to three axes originating in a common point, two in the horizontal plane and one that is vertical. On the plane of the projection, *i.e.*, the plane of the paper on which the diagram is drawn, these three axes may be separated at any angle provided their sum is 360°. The commonest is isometric projection in which the interaxial angles are 120° and equal to each other. W. H. Wilson[8] has made good use of axial angles of 135°, 135°, and 90° to give more fore-shortening to a block than could be had with isometric projection. It can be safely said, however, that the novice in constructing block diagrams had best begin with an isometric projection and depart from it only in special cases. A perspective projection of a mine is rarely worth the increased constructional labor, and in addition, in perspective projections it is difficult to scale or compute distances from one point to another in the diagram.

ISOMETRIC PROJECTION.

Lobeck[9] lists the following general rules of isometric projection:

[7] Nolan, T. B.: The underground geology of the Tonopah Mining District, Nevada. Univ. Nev. Bull., vol. 29, no. 5, pls. 1 and 2, 1935.

[8] Wilson, W. H.: *Op. cit.*, pp. 562–566.

[9] Lobeck, A. K.: *Op. cit.*, pp. 120–121

"1. Measurements may be made to scale anywhere upon the upper surface of the block in the direction of either of the two coordinates, which in the object itself are at right angles to each other.

"2. Distances in other directions are not commensurate with each other unless measured along lines parallel to each other, and they are not commensurate with distances measured on the sides of the block.

"3. All lines parallel in the object itself are parallel in the isometric drawing.

"4. All lines vertical in the object are vertical in the drawing.

"5. If the vertical scale of the drawing is the same as its horizontal scale, then the measurements made in the direction of any of the three coordinates are commensurate.

"6. All angles in an isometric drawing are distorted, and even two angles lying in the same plane cannot be compared with each other unless they lie in exactly similar positions."

USE OF ISOMETRIC PAPER.

Isometric cross section paper in sheets 12 × 18 inches in size can be obtained from most drafting supply houses.[10] Its use is illustrated in Figs. 1, 2, and 3.

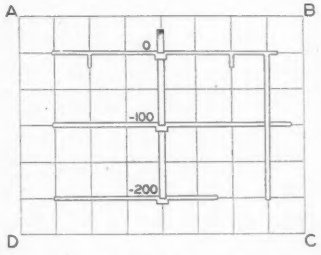

FIG. 1. Horizontal plan of a mine with rectilinear coordinates.

[10] Eugene Dietzen Co., Chicago, No. 358A. Keuffel and Esser Co., New York, No. 342C.

Fig. 1 shows a horizontal plan of a very simple mine with rectilinear coordinates. In Fig. 2 the coordinates have been transferred to isometric paper. Each level has its own set of horizontal coordinates separated on the vertical coordinate by the vertical distance between levels (A to A' and A' to A''). Only the workings on the O level have been drawn. In Fig. 3 the block diagram has been completed by drawing in the workings on the

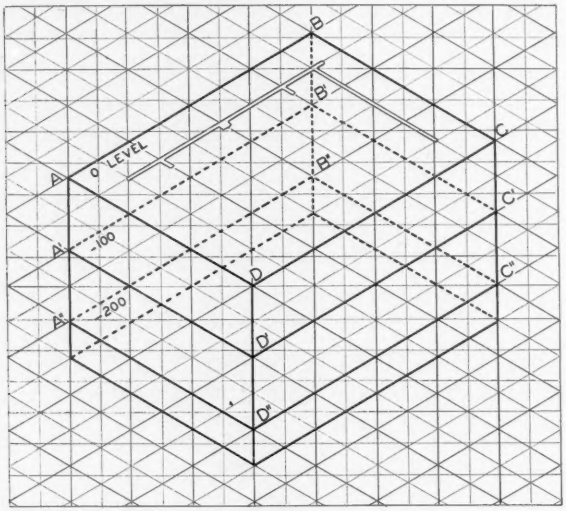

FIG. 2. The coordinates of the mine transferred to isometric paper. Only the workings on the O level have been drawn in.

other levels and outlining the shelves and vertical faces on the block. It is now ready for plotting geologic features.

The isometric paper method has the advantage of requiring no special apparatus and for small mines that require the plotting of relatively few points it is perhaps the simplest one. For large mines with irregular workings the method is unduly laborious.

Fig. 4, a diagram of the May Day and Idaho Mines in the La

Plata district, Colorado, by Eckel,[11] was originally drawn on co-ordinate paper.

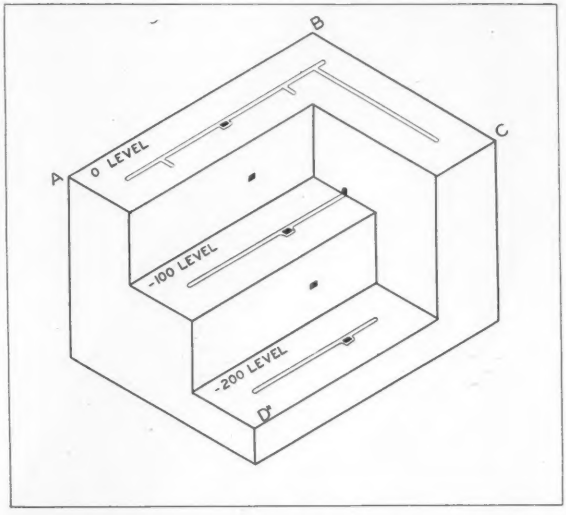

FIG. 3. The block diagram completed by drawing in the shelves and vertical faces.

DUFOUR'S ISOMETROGRAPH.

There are, however, many short cuts in making isometric block diagrams. Dufour[12] devised the instrument shown in Fig. 5. A long rod carrying a stylus (e) and a pencil (h) is pivoted at one end and the pivot slides in a horizontal groove. The device can be of any size (provided the distance between the stylus and the pivot (ek) is unity and the distance between the pencil and

[11] Eckel, Edwin B.: Resurvey of the geology and ore deposits of the La Plata mining district, Colorado. Colo. Scientific Soc. Proc., vol. 13, pl. 2, p. 544, 1936.

[12] Dufour, P. T.: Les perspectives-reliefs, nouveau procédé permettant de les obtenir par simple transposition automatique et projection oblique des formes du terrain représentées sur les cartes hypsométriques. Revue de Geographie, Annuelle, 1916–18, vol. 8, no. 4, Paris, 1917.

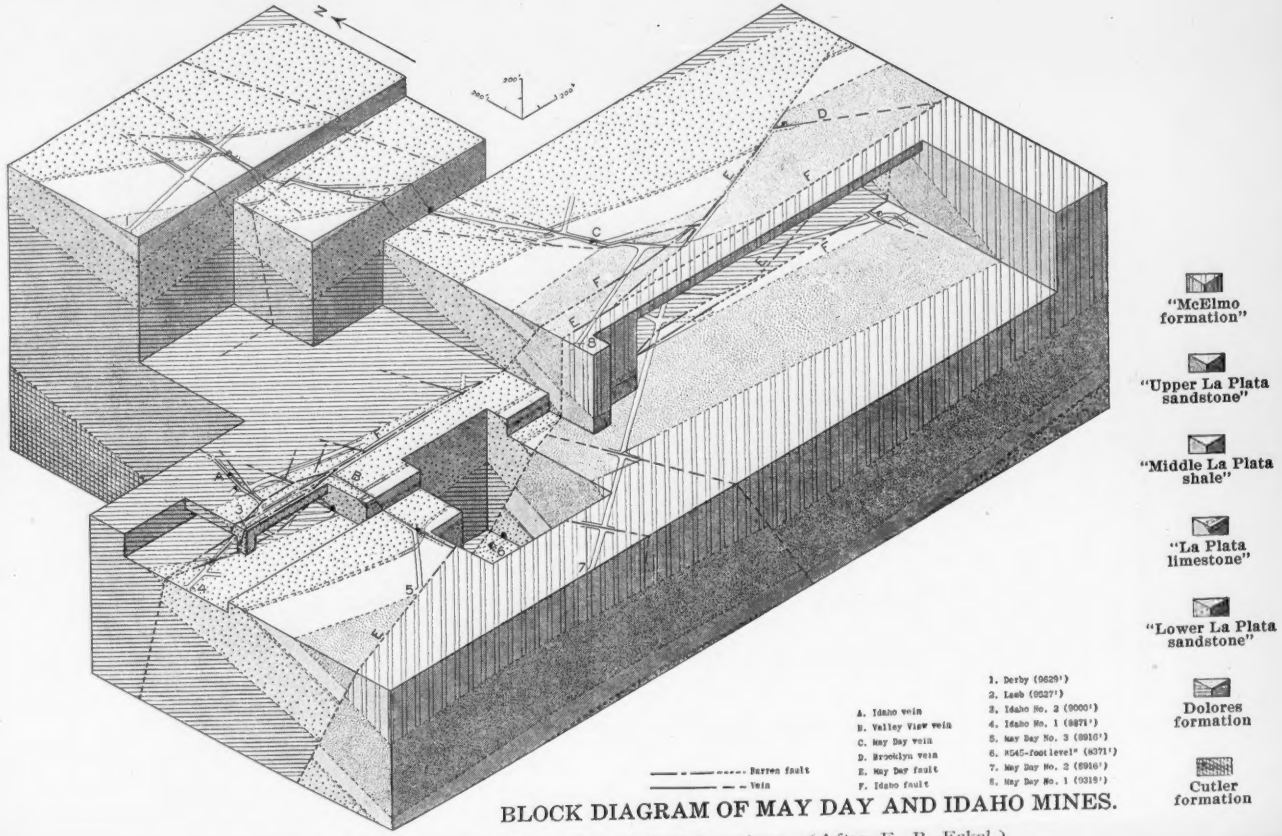

FIG. 4. Block diagram of May Day and Idaho mines. (After E. B. Eckel.)

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the pivot (hk) is $\frac{1}{\sqrt{3}} = .577$. When the stylus is moved vertically the pencil moves only .577 the distance travelled by the stylus. That combination of movements will transform the square $ABCD$ into the isometric lozenge $A'\ B'\ C'\ D'$. Vertical intervals are obtained by sliding the paper, on which the isometric drawing is being made, up and down as suggested by dotted lines. Thus, moving the paper the distance xy permits construction of the lozenge partly represented by $A''\ C''\ D''$.

Fig. 6 is a horizontal projection of a mine near Virginia City, Nevada. From it the block diagram, shown in Fig. 7, was made

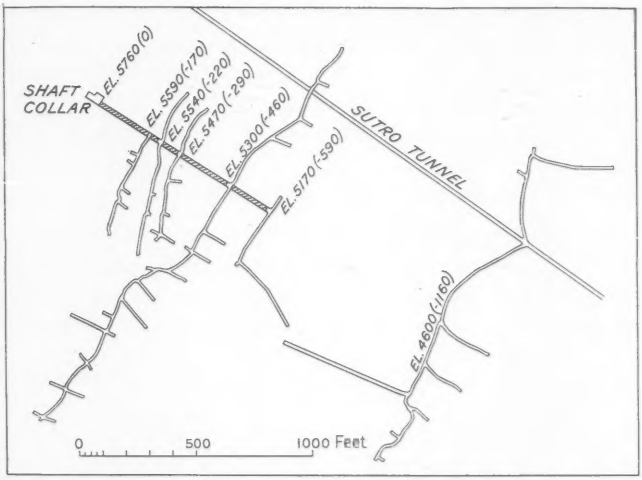


FIG. 6. Horizontal projection of a mine near Virginia City, Nevada.

by means of the device just described. The drawing time, exclusive of inking, was a little less than a half hour—which is a fraction of the time required to draw the same block diagram on isometric paper and much less laborious.

A variation of the Dufour device consists of the substitution of a swinging arm for the horizontal groove shown in Fig. 5.

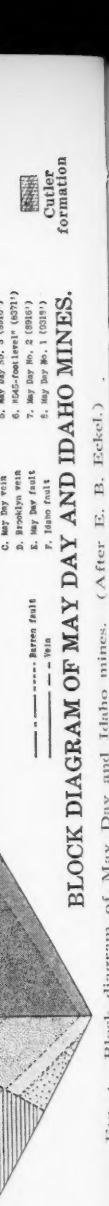


FIG. 4. Block diagram of May Day and Idaho mines. (After E. B. Eckel.)

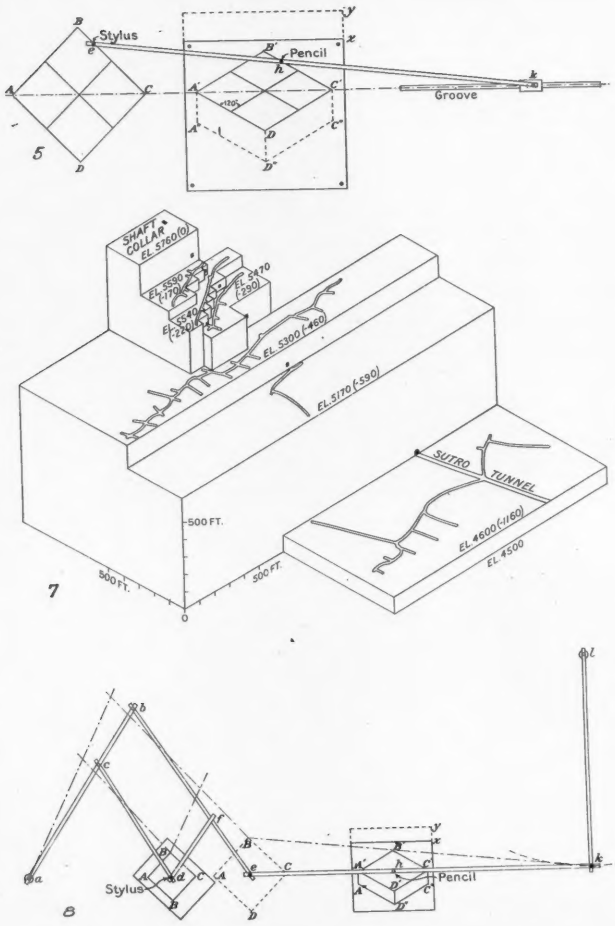


FIG. 5. The Dufour isometrograph.

FIG. 7. Isometric block diagram of the mine near Virginia City, Nevada, made with the Dufour isometrograph.

FIG. 8. A variation of Dufour's device wherein a swinging arm has been substituted for the groove in which the pivot moves and an ordinary pantograph is added at the tracing stylus. This arrangement as illustrated transforms a plan into an isometric drawing enlarged 2 diameters.

The arm is simpler and easier to construct than the groove, but has the disadvantage of adding to the curvilinear distortion. The instrument may also be combined with a pantograph, as shown in Fig. 8, on which also the swinging arm has been substituted for the groove. With this arrangement the plan *ABCD* is traced with the stylus of the pantograph (*d*), enlarged to two diameters at e and transformed into isometric projection at A'B'C'D'. The topography on the block diagram shown in Fig. 9 was drawn in isometric projection by using this device with a $\times$ 6 enlargement at the pantograph.

In using either of these devices in making block diagrams the mine plan remains fastened to the drawing board and the paper on which the diagram is being drawn is moved up or down against a straight edge that bears the vertical scale and is firmly attached to the drawing board.

The great objection to both devices is the curvilinear distortion imposed upon the drawing by the radial motion of the arms.

THE LINK SYSTEM OF PEAUCELLIER.

As a method for overcoming the curvilinear distortion of his simple isometrograph, Dufour incorporated the Peaucellier [13] link system (Fig. 10) into his device (Fig. 11) and added two additional links, *GH* and *KH*, jointed at *H* and parallel respectively to *BC* and *DC*. Points *G* and *K* are such that $\frac{FG}{FB} = \frac{FK}{FD} = \frac{1}{\sqrt{3}} = .577$. If a stylus is mounted at the joint *C* and a pencil at the joint *H*, a vertical line traced by *C* is reduced at *H* in the ratio 1 to .577. If the base *FE* is mounted on a horizontal track so that horizontal movement can be transferred from *C* to *H* without distortion, it may be used as an isometrograph just as the simple devices of Dufour.

[13] Kemp, A. B.: How to draw a straight line, a lecture on linkages, pp. 12–19, MacMillan Co., London, 1877.

Copies of this interesting little book are in the Library of Congress and the John Crerar library.

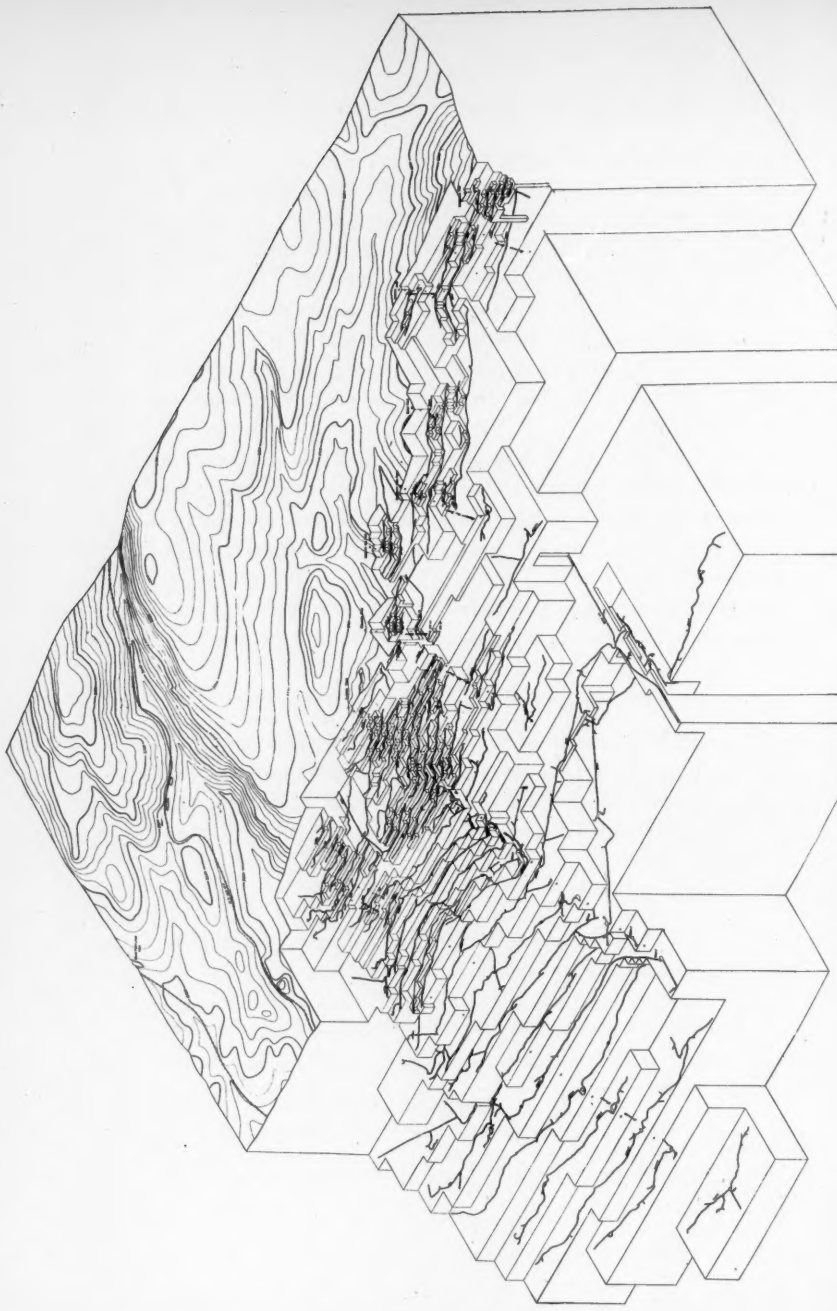


FIG. 9. Isometric block diagram of a large mine. The original drawing is 8 feet long.

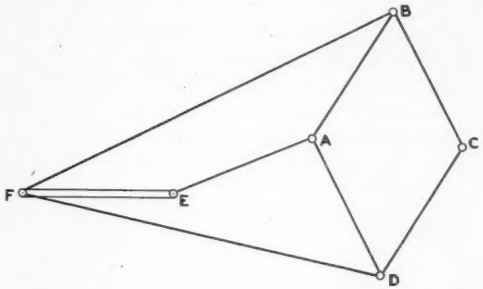


FIG. 10. The link system of Peaucellier. The joint *C* moves in a straight line perpendicular to the fixed base *FE*.

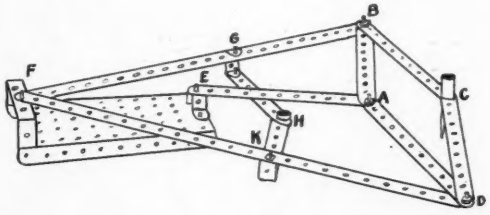


FIG. 11. Dufour's adaptation of the Peaucellier link system. The model is built from "Mecanno" parts.

THE WENTWORTH ISOMETROGRAPH.

Several years ago C. K. Wentworth devised an isometrograph of the Dufour type mounted on a movable carriage running on a horizontal track. W. H. Bradley and J. B. Mertie, Jr., of the Geological Survey, added Dufour's parallel motion linkage to the Wentworth model and substituted a trackless carriage for the rails. The instrument shown in Figs. 12 to 14 was constructed in the instrument shop of the Geological Survey under the direction of R. L. Atkinson in February, 1933.

Mr. Bradley kindly furnished the following notes on this isometrograph:

FIG. 9. Isometric block diagram of a large mine. The original drawing is 8 feet long.

The Link System (*Figs. 12 and 13*).—The link, stylus, and supporting posts are made of stainless steel and the other parts of brass. The joints have mechanical thin spring washers of phosphor bronze and are so constructed that there is no play in the link system. As wear develops it can be taken up. The length between drill holes of the four equal links forming the rhombus is 8 inches, the total length between end holes of the two long links is 20.444 inches. Other dimensions are given in Fig. 12.

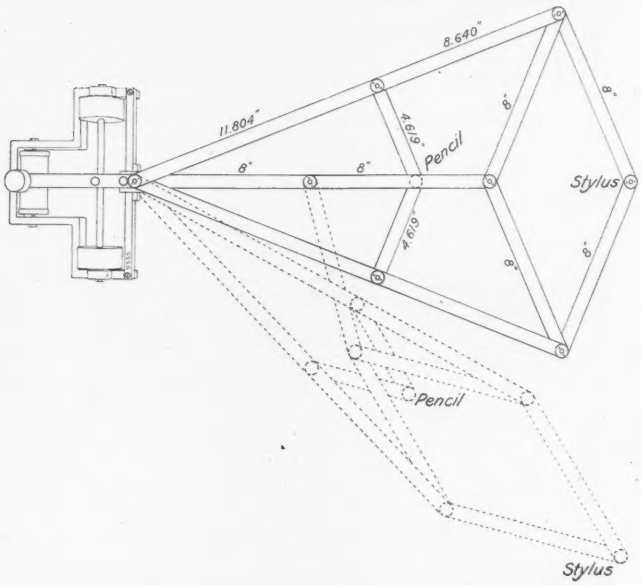
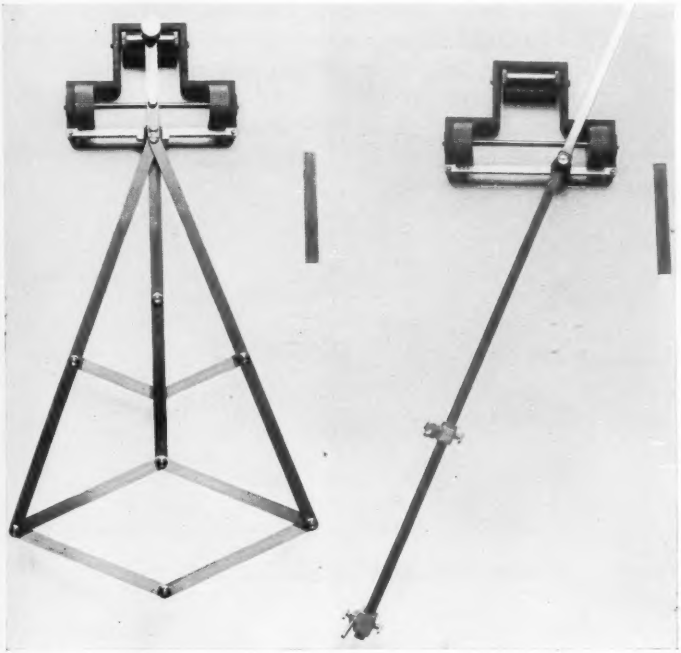


FIG. 12. Plan drawing of the Wentworth isometrograph showing the link system in two positions. The dimensions are between drill holes.

The Carriage (*Figs. 12 and 13*).—The trackless carriage is provided with a "contour bar" so that vertical intervals can be set off without moving either machine, drawing, or copy by sliding the link system up or down along the bar. The carriage must be used on a perfectly flat surface, otherwise it creeps and the diagram is distorted.

The Single Arm (*Fig. 14*).—The Wentworth device is provided with a single arm of the Dufour type which is interchangeable with the link system. The arm is provided with movable pivot, stylus, and pencil.

Although the single arm is not free from curvilinear distortion, it is useful for constructing diagrams with a lower angle of view than that of an isometric projection. Such projections are particularly useful in making landscape sketches from topographic maps.



13 14

FIG. 13. Photograph of the Wentworth isometrograph showing the link system and the trackless carriage.

FIG. 14. Photograph of the Wentworth isometrograph provided with the single arm in place of the link system.

A model of the Wentworth isometrograph capable of transferring larger mine maps would better suit the needs of the mining geologist than the one described. The same design, however, could well be used.

THE WILSON TRI-DIMENSIONAL DEVICE.

W. H. Wilson[14] has devised an instrument that is essentially a modification of the Wentworth isometrograph, and which he has used in the preparation of a three-dimensional map of the extensive mine workings of the Kolar gold field in India (Figs. 15 and 16). The chief changes are the use of a fixed track instead of a trackless carriage; slightly longer side arms (24 inches as

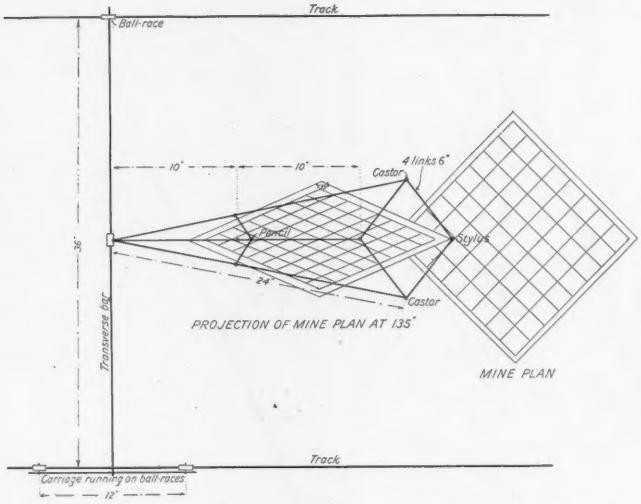


FIG. 15. Plan showing chief dimensions of the Wilson tri-dimensional device. Reproduced by permission of the Secretary, Inst. Min. and Met.

against 20.444); and an arrangement that permits the construction of projections at both 120° (isometric) and 135°. This is accomplished by drilling in the side arms at proper distances two sets of holes in which are fastened the short links carrying the pencil. The short links have slots which permit their adjustment for either projection. This is a decidedly useful innovation for a

[14] Wilson, W. H.: Tri-dimensional mapping of extensive mine workings, with special reference to those of the Kolar gold field. Inst. Min. and Met. (London), Bull. 378, pp. 1–17, March, 1936; Trans., vol. 45, 1937.

lower angle of view, *i.e.*, a greater foreshortening than that given by axial angles of 120°, is often desirable. For vertical intervals the link system can be adjusted up and down a vertical spacing bar. Wilson's article contains details of the construction of his instrument. Both it and his earlier paper deserve the attention of those contemplating the construction of block diagrams.

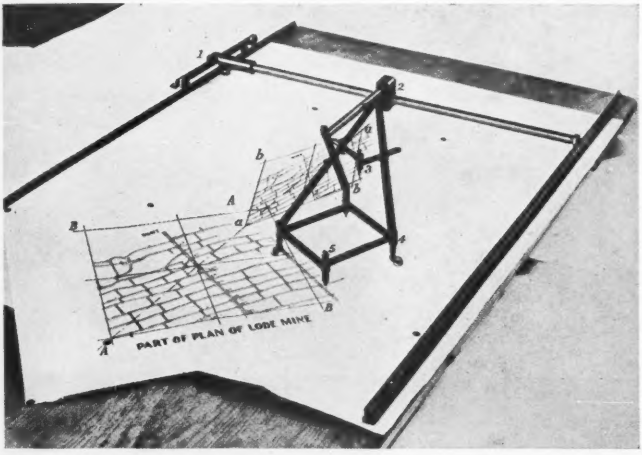


FIG. 16. Photograph of Wilson's tri-dimensional instrument, shown in operation. Reproduced by permission of the Secretary, Inst. Min. and Met.

VAN DER HOOP DEVICE.

Another type of tri-dimensional device based upon a different link system was recently described by Van der Hoop[15] and is illustrated in Figs. 17 and 18. His link system consists of four arms *CF, FG, HK,* and *HD,* which are pivoted at *E, H, G,* and *F* and carry a stylus at *K* and a pencil at *I*. The ends *C* and *D* are mounted on rollers that move horizontally in the fixed track *AB*

[15] Van der Hoop, Dr. A. N. J. Th. A. Th.: Een toestel voor het teekenen van block-diagrammen. Koninklijk Nederlandsch Aardrijkskundig Genootschap, Tijdschrift, pp. 3–14, Jan., 1934.

(Fig. 18) and permit horizontal motion to be transferred from the stylus K to the pencil I without distortion.

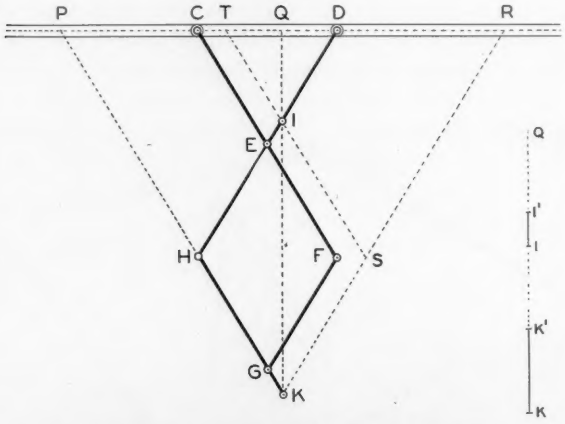


FIG. 17. Diagram of the Van der Hoop device.

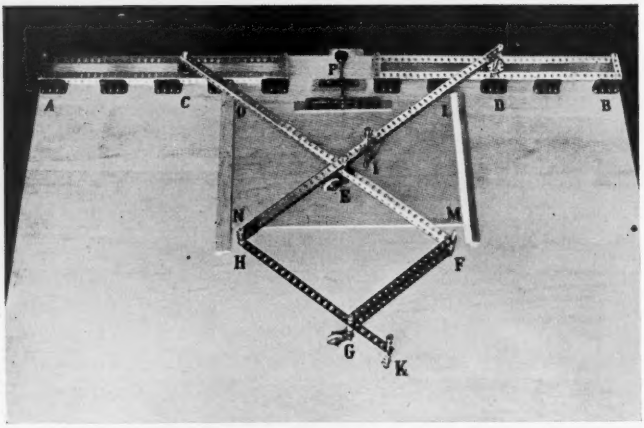


FIG. 18. Photograph of a model of the Van der Hoop device constructed from "Meccano" parts. The stylus is at K and the pencil at I.

Vertical motion is transformed by the link system. When the stylus (Fig. 17) is moved from K to K' the pencil moves from I to I'. The ratio of transformation is determined by the ratio $\frac{DI}{DH + HK}$ for $DH + HK = RK$.

In the similar triangles QID and QKR

$$\frac{QI}{QK} = \frac{DI}{RK} \text{ and } \frac{QI'}{QK'} = \frac{DI}{RK}\text{; thus } \frac{II'}{KK'} = \frac{DI}{RK}\text{, or } \frac{II'}{KK'} = \frac{DI}{DH+HK}.$$

As is shown in Fig. 18, motion on the vertical axis of the projection, *i.e.*, differences in elevation, are obtained by means of a

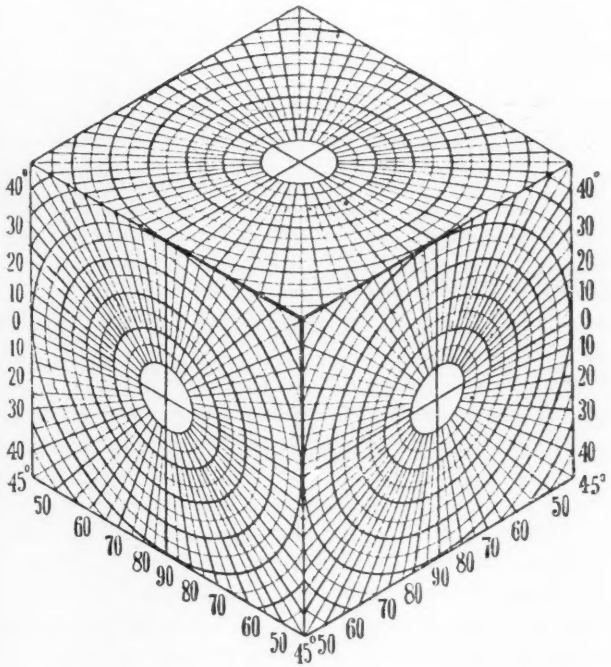


FIG. 19. Isometric protractor.

movable drawing board sliding in grooves against a scale LM and controlled by the screw feed P.

Although we have not constructed one of the Van der Hoop instruments and so have no experience in its use, the mechanical principles seem best adapted to making block diagrams having a low angle of view.

ISOMETRIC PROTRACTOR.

The isometric protractor, illustrated in Fig. 19, is used in measuring dip and strike on isometric projections. Such a protractor of celluloid is made by F. W. Breithaupt and Sohn, Cassel, Germany, and is described in their pamphlet "Anleitung zum Gebrauch des Stach'schen Steropapiers and Sterotransporteurs."

CONCLUSIONS.

Our purpose in reviewing this assortment of devices is to emphasize the fact that much of the drudgery of constructing block diagrams by the usual isometric paper methods can be avoided. If the block diagram to be constructed is to be used simply as an idea sheet, curvilinear distortion is relatively unimportant and the simple Dufour device may be used. If, on the other hand, accuracy is desired, one of the methods involving the link system should be employed.

Lest our account make construction seem too easy, a few words of caution are in order. The type of diagram we have emphasized is best adapted to dipping structures, whether beds, stopes, veins, or fractures, and is not suitable for illustrating mines in which the levels are vertically superposed. The choice of a viewpoint requires some care. Usually it is best to view the diagram as nearly perpendicular to the principal structure as is possible.

The choice of shelves and vertical walls is made by the cut-and-try method. First lay out the shelves so as to show the maximum of workings on each level and then sacrifice workings where structure can not otherwise be shown.

When studying a new mine it is often worth while first to construct a block diagram of the mine workings and on it plot the geology—day by day—as the mine is mapped. The growing diagram gives a good check on underground observations, for each vein, split, fault, and contact must be accounted for in space, and structural interpretations or correlations are suggested and others automatically rejected by the diagram itself.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
April 29, 1937.

USE OF THE MICROSCOPE TO DISCOVER FAULTS CUT BY DIAMOND DRILL HOLES.

EDWARD WISSER.

ABSTRACT.

Significant fine-textured micro-fracture patterns exist in the wall rocks near faults in the Pachuca district, Mexico, and such patterns are absent from the same rock distant from the faults. The chances are 9 to 1 that strong micro-fracturing comes from within 20 m. of a fault. Thus, the micro-fracturing is due to stresses operative during faulting. Hence thin sections disclose the presence of faults. In drill cores it is often difficult to distinguish fault material from ordinary broken core, because gouge that indicates faulting may be washed away by drill water. Thin sections, however, will indicate whether the crushed material represents a fault or not; likewise the presence of fault veins can be detected.

THE interpretation of diamond drill cores has by necessity occupied a part of the writer's attention for several years. A previous paper [1] presented a series of charts showing all possible vein attitudes corresponding to any given angle between the vein and the drill hole, for various inclinations of the hole. It was shown that these charts have value in suggesting the probable attitudes of veins cut by drill holes where the core-vein angle can be measured.

The present paper attempts to add another bit to the technique of drill core interpretation in mining districts.

Donald M. Fraser, in a paper [2] published some years ago, described a method for the determination of fault movements by the examination of properly oriented thin sections of the wall rock close to the fault plane. He selected a fault, on which the direction and extent of the movement were known and cut samples from the hangingwall and footwall blocks, close to the fault sur-

[1] Wisser, Edward: An aid in the interpretation of diamond drill cores. ECON. GEOL., vol. 27, no. 5, 1932.

[2] Fraser, D. M.: Interpretation of fault movements from mineral fractures. Eng. & Min. J., vol. 133, no. 12, 1932.

face. The orientation of each sample with respect to the fault surface was carefully preserved, so that thin sections could be made perpendicular to the fault plane and parallel to the striae on that plane. Such sections should contain the major and minor axes of the ellipsoid of deformation corresponding to the stresses set up in the wall rock by the movement on the fault surface.

The country rock in Fraser's test is biotite gneiss. He noted in his study of the thin sections that the mineral grains were often broken along relatively smooth planes; in the case of biotite, such planes in places intersected the cleavage. The traces of these fracture planes in some instances occurred in groups roughly parallel to a given direction, forming a set. In places two sets occurred, intersecting each other within a mineral grain. Rarely microscopic drag was seen, indicating the direction of movement along a tiny fault. Small folds, in places overturned, were noted in the incompetent biotite.

From data such as the above, Fraser deduced the directions of maximum stress for the areas from which the specimens were taken, and these were found to agree with the previously determined stress directions along the fault. The conclusion is reached that where the nature of the fault movement is unknown, examination of oriented thin sections taken from the walls may throw light on the problem.

The writer is not here concerned with criticism of Fraser's conceptions of stress and strain. It is sufficient for the present purpose to note that a fracture pattern suggestive of compression or shear was set up in the walls of a fault of marked displacement. Unfortunately, it does not appear from Fraser's paper that any thin sections were examined from areas well away from the fault, to guard against the possibility that the fracture pattern observed was regional and not localized by the fault stresses.

MICROSCOPIC FRACTURING OF WALL ROCK IN RELATION TO FAULTING AT PACHUCA, MEXICO.

After reading Fraser's paper, the writer was curious to see whether any significant fine-textured fracture patterns were set

up in the wall rocks near faults in the Pachuca silver district, and if so, how far away from such faults micro-fracturing persisted. The job was an easy one, because, first, numerous long crosscuts are the rule, and counterdrives abundant; second, the displacements on most of the faults had been worked out; third, wall rock specimens, from most of which thin sections had already been made, were available. These were taken at systematic intervals, generally 10 m., along most of the crosscuts and counterdrives, and without regard for faults and veins. These specimens give an impartial picture of the wall rock; its appearance close to faults could be contrasted with that well away from them.

Time was not available for the taking of oriented rock specimens. The investigation was therefore limited to a search of the available thin sections for microscopic fracture patterns, and a brief study of the distribution of the specimens that showed such patterns.

The country rock at Pachuca is predominantly augite-andesite. The rock is markedly porphyritic and the chief phenocrysts are plagioclase and augite. Sparse phenocrysts of quartz occur in some horizons. The size of the phenocrysts varies, but an average length for the plagioclase might be 3–4 mm. The groundmass is generally glassy, rarely microcrystalline. The rock shows propylitization away from important veins; close to such veins sericitization and silicification are dominant. For a more detailed description of the rock formations at Pachuca the reader is referred to a recent paper [3] by the author.

The specimens that furnished the thin sections examined were taken from places distributed with some uniformity over the Pachuca area; a few came from the Real del Monte area. (See Fig. 2 of the paper just cited.) The principal faults of the Pachuca area (most of them veins as well) strike roughly east-west. Their spacing is irregular, but the distance from one major fault to the next is of the order of 500 m. The main movements on most of the faults were " normal," the hangingwall

[3] Wisser, Edward: Formation of the north-south fractures of the Real del Monte area, Pachuca silver district, Mexico. Am. Inst. Min. Met. Engrs. Tech. Pub., no. 753–I. 63, November, 1936.

having moved down with respect to the footwall. Later, minor horizontal movements took place along some of these faults.

The faulting on the Vizcaina fault was pivotal, with the pivotal-axis between the Pachuca area and the Real del Monte area, and the attitude of the fault and nature of the movement such that the faulting at Pachuca was "reversed." In that portion of the Real del Monte area studied, the faulting was horizontal and minor. Three different types of faulting are, then, represented in the areas studied.

All three types set up microscopic fracture patterns near them in the wall rocks. A single type of pattern predominates for all three types of faults. This consists of two sets of fracture planes, intersecting at angles varying from 45 to 80 degrees. The thin sections, oriented at random, rarely show the true angle between the traces of the planes. In general the angle seen is less than the true angle.

Some of the two sets of planes are equally developed. In places one set is strong, the other feeble. In other places one set only appears.

The fracture sets appear chiefly in the plagioclase phenocrysts. Where the fracturing is severe, they pass through phenocryst and groundmass alike. In places the fractures are filled with quartz or carbonate; elsewhere the feldspar (usually andesine-labradorite originally) has altered to albite along the fracture planes.

The quartz phenocrysts only rarely show fracturing along simple planes. They are as a rule irregularly fractured, or shattered to form mosaic areas. Where the plagioclase phenocrysts show fractures but not the quartz phenocrysts, the latter often show strong interference strain effects. Augite phenocrysts fracture like the plagioclase, but less readily.

The specimens, unoriented as they are, throw no light on the possibility that the micro-fracture patterns are miniatures of the coarser mapped patterns for their areas, in position as well as appearance. In appearance they resemble the coarser patterns seen in the mine workings, in several cases.

Several hundred thin sections were examined, made from the more or less uniformly distributed specimens described. Of these, 109 showed some degree of fracturing. Table I shows the positions of these thin sections with respect to faults.

TABLE I.

LOCATION OF ALL SPECIMENS (109) THAT SHOW MICRO-FRACTURING.

Horizontal Distance from Fault, Measured Normal to Strike, Meters.	Number of Thin Sections.	% of Total (109).
0–10	67	61.5
11–20	12	11.0
21–50	9	8.2
51–130	5	4.6
Over 130; presumably unrelated to any fault	16	14.7
	109	100.0%

The relation of microscopic fracture patterns to faulting is obvious, especially if the average distance of 500 m. between faults is kept in mind. It is true that a number of thin sections taken close to faults showed no micro-fracturing; but in some cases the sections were probably so cut as not to reveal the fracturing, and it is also probable that the fracturing is not uniformly distributed. The point is that nearly three-quarters of the specimens that do show fracturing came from places less than 20 m. from a fault, and that large blocks of ground away from faults, and proportionately represented in the group of specimens, show no fracturing whatever.

Table II deals with the 37 thin sections that show the strongest

TABLE II.

LOCATION OF THE 37 SPECIMENS THAT SHOW STRONG MICRO-FRACTURING.

Horizontal Distance from Fault, as in Table I.	Number of Thin Sections.	% of Total (37).
0–10	32	86.5
11–20	2	5.4
21–50	2	5.4
Not related to known fault	1	2.7
	37	100.0%

micro-fracturing. The relation of this group to faulting is considerably more striking than that shown in Table I.

Thus, in the areas studied, where strong micro-fracturing is seen, the chances are 9 to 1 that the specimen exhibiting it lies within 20 m. of a fault.

The faults involved may be roughly classified as strong and weak. The displacements on the strong faults exceed 30 meters, and such faults are generally accompanied by much gouge, crushed zones, or other evidence of intense tectonic stress. The weak faults have less displacement and show less stress.

Tables III A and III B show the distribution of strong and weak micro-fracturing related to strong faults (III A) and to weak faults (III B).

TABLE III *A*.

LOCATION OF STRONG AND WEAK MICRO-FRACTURING RELATED TO STRONG FAULTS.

Hor. Dist. from Fault.	Strong Micro-fracturing. (28 Thin Sections).		Weak Micro-fracturing. (43 Thin Sections).	
	No. of Thin Sec.	% of Total.	No. of Thin Sec.	% of Total.
0–10 m.	24	85.8	23	53.5
11–20	2	7.1	10	23.3
21–50	2	7.1	5	11.6
51–130			5	11.6
	28	100.0%	43	100.0%

TABLE III *B*.

LOCATION OF STRONG AND WEAK MICRO-FRACTURING WITH RESPECT TO WEAK FAULTS.

Hor. Dist. from Fault.	Strong Micro-fracturing. (8 Thin Sections).		Weak Micro-fracturing. (14 Thin Sections).	
	No. of Thin Sec.	% of Total.	No. of Thin Sec.	% of Total.
0–10	8	100.0	12	85.7
21–50			2	14.3
	8	100.0%	14	100.0%

These tables show that both strong and weak micro-fracturing occurs most abundantly close to both strong and weak faults.

With strong faults, the zone of micro-fracturing is wide, and the weaker effects extend farther from the fault surface than do the stronger. With weak faults strong microfracturing is limited entirely to the close proximity of the fault, and weak fracturing is nearly as closely limited. Such results accord with the notion that the micro-fracturing was set up by stresses operative during the faulting.

Incidentally, out of 79 thin sections that show micro-fracturing related to faults other than vertical, 39 came from footwall blocks and 40 from hangingwall blocks.

APPLICATION TO DISCOVERY OF FAULTS IN DRILL HOLES.

With good core recovery, drill cores give fairly accurate pictures of veins that do not closely parallel the hole. The determination of barren faults in drill holes is often economically important, and usually difficult. Where good formation markers exist, they will not appear in the hole unless the latter cuts across the formations in a marked way. In rocks without markers, such as hard, massive andesite, a fault may readily escape one's notice. Direct evidence of faulting shown by cores is characteristically unreliable. Local areas of softening in andesite make perfect pseudo-gouge, which often cores. Drilling difficulties commonly result in shattering of the rock, and drilling through shattered rock is likely to round off the fragments, resulting in artificial attrition pebbles that resemble those due to fault movement. In checking up on many drill holes by inspection of crosscuts driven along the courses of holes, the writer has been astounded at the frequency with which nearly unfractured ground has looked, in the corresponding drill hole, like a heavily faulted zone. On the other hand, scores of important faults passed quite unnoticed in drill holes. This was due in large part to the fact that clayey gouge has a tendency to wash out in the sludge, and that in default of any visible gouge or gouge-cemented fault breccia, shattered core and even rounded fragments were ascribed to difficulties in drilling.

As a rule, important faults do show up in drill cores, chiefly as broken core commonly accompanied by remnants of the fault

gouge; the difficulty has been that unimportant slips, lightly fractured ground or difficult drilling may give precisely the same effects, and no means have been at hand to identify the particular effects caused by faulting.

If the results of the study described in this paper are valid, the making of thin sections at frequent intervals along those portions of the core that suggest faulting should show both strong and weak micro-fracturing close to strong and weak faults; with strong faults, the strong micro-fracturing should persist in spots for some distance away from the fault surface, the weak micro-fracturing for a considerable distance; with weaker faults, any micro-fracturing should be closely confined to the neighborhood of the fault. The actual fault surface should lie very close to the greatest intensity of micro-fracturing observed, and provided some other evidence such as strong shattering of the core occurs at this place, the fault can be spotted with accuracy. At the worst, the position of the fault should be estimated within about 40 meters of the true position, since the most intense micro-fracturing appears to be limited to a band about 40 meters wide, with the fault near the center line.

The method has little or no value where nothing is known of the faulting in the area drilled. It discloses neither the attitude of the fault nor the amount and direction of the displacement. But where a hole is drilled in such a way that the prolongation of a fault, the displacement on which is known, might be crossed, shattering of the core combined with intense micro-fracturing will probably suggest the position of the fault in the hole. Conversely, the absence of any micro-fracturing in the core would point to the probability that the fault has not been crossed.

Specific instances where the method would be of value are not difficult to imagine. A hole is drilled to cut a vein; owing to operating requirements, it is necessary to drill in such a manner that a fault heading into the area might cross the hole not far from where the vein should be cut. If the fault is encountered, but no vein, it may be that the displacement on the fault, combined with the attitudes of the fault and vein, have caused the vein

to be cut out entirely from the line of the drillhole. With no knowledge concerning the fault, it might be assumed that the vein has pinched out; knowing the position, attitude and displacement of the fault, and the probable position of the vein before faulting, obtained by simply projecting it to the drill hole without regard to the fault, the position of the vein after faulting may be worked out, and another hole aligned to cut it.

The method has a less direct, but a wider application. In the exploration of a complicated mining district with many veins and faults, it is of prime importance to decipher the vein and fault pattern. Where the veins are persistent and little faulted, and mine workings and drill holes are extensive, the writer has had little difficulty in working out the vein pattern, using the drill holes as adjuncts to the mine workings. But working out the fault pattern where much of the area is explored by long drill holes only has turned out to be quite another matter. In the search for ore, a knowledge of the faulting is often quite as important as a knowledge of the vein system. The writer believes that in the Pachuca district the use of the method described would increase considerably the understanding of the fault pattern. Application to other districts would always be preceded by a study similar to that described in this paper.

Acknowledgments.—The writer desires to thank Mr. M. H. Kuryla, Managing Director of the Cia. de Real del Monte y Pachuca, for permission to publish this paper.

MANILA, P. I.,
May 5, 1937.

HUDSON BAY MOUNTAIN, BRITISH COLUMBIA.

FORREST A. KERR.

ABSTRACT.

Hudson Bay Mountain is largely a complex of Jurassic volcanic rocks. It probably has a granitic core of Tertiary age and it is partially covered and was formerly probably entirely covered by a dome of Lower Cretaceous sediments. Mineral deposits related to the granitic core occur for the most part in radial and other fractures in a shallow zone directly under the remnants of the Lower Cretaceous and in nearby areas where this formation has only recently been removed by erosion.

GENERAL GEOLOGY.

HUDSON BAY MOUNTAIN is in the Bulkley Mountains east of the Coast Range in the Skeena River drainage basin, in British Columbia (Fig. 1). It forms part of a magnificent isolated group of mountains that rise from surrounding low areas with an elevation from about 1,500 feet to somewhat over 3,000 feet. This group occupies a diamond-shaped area about 18 miles long and 12 miles across. It has four main peaks roughly in the four corners of the diamond but the outstanding part of the group is the southern peak, Hudson Bay Mountain, which rises to 8,500 feet and is separated from the other peaks by a large valley with a divide of slightly over 5,000 feet elevation.

The mountain is made up largely of massive volcanic rocks with some bedded volcanic and sedimentary rocks (Fig. 2). Some of these sediments are of Jurassic age. All of these rocks are complexly folded. The low areas around the southern part of the mountain are largely drift-covered, but in places soft sediments of the Skeena formation of Lower Cretaceous age are exposed. They may be fairly continuous in the drift-covered areas as well. They extend up the eastern slope of the mountain in a thin shell to within about 1,000 feet of the peak and have an outward dip slightly greater than the slope of the mountain. At

the base the formation is probably about 1,000 feet thick. From the eastern slope it continues to the northern slope where the strata dip northward. On the north side of the valley that bounds Hudson Bay Mountain, the Skeena formation is overlain by a series of massive volcanic rocks. These Jones [1] classed as older than the Skeena formation but the writer considers them to be younger and unconformably above the Skeena formation and, therefore,

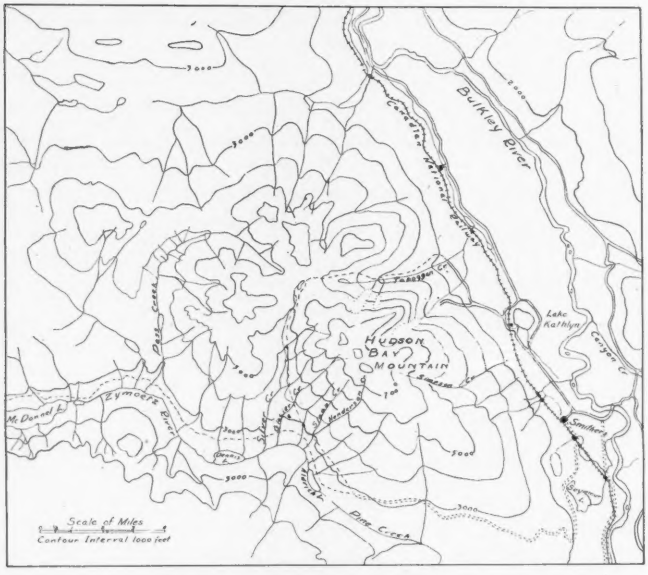


FIG. 1. Hudson Bay Mountain and Adjacent Peaks.

probably of Upper Cretaceous age. According to the writer's interpretation, toward the west this unconformity cuts out the Skeena formation and the younger volcanic rocks lie upon the older. On the west side of the mountain the Skeena formation continues up the slope for about 1,000 feet and dips away from

[1] Jones, R. H. B.: Hudson Bay Mountain. Can. Geol. Surv., Sum. Rept. pt. A, p. 120, 1925.

the mountain at about 60 degrees. At the base of this slope, and in the valley, the formation is probably several hundred feet thick. On the east slope, a change in facies of the Skeena formation is noted as one ascends the mountain, but this is not due to successive overlap toward the peak. There is nothing to suggest that the formation originally thinned to any marked degree toward the peak. Therefore, it is considered that it once covered the mountain in a dome shape.

The Skeena formation in the lowlands is largely soft sandstones, shales, conglomerate, bituminous coal and probably some tuffs. The basal section is in part conglomerate but contains much shale. The matrix of the conglomerate in places is black shale. Up the slope of the mountain, the rocks are quartzites and argillites instead of sandstone and shale and carry anthracite and graphitic anthracite and schist.

On the peak north of Hudson Bay Mountain a small granitic mass cuts the volcanic series considered to be younger than the Skeena formation, and south of the mountain a granitic knob rises from lowlands occupied by the Skeena formation. Some other small masses of granitic rocks are exposed on the mountain. On the eastern slope, the mountain is deeply incised by an existing glacier, which covers the underlying bed rock. The stream coming from this glacier, however, carries so many granitic boulders that it suggests that a granitic body is being eroded by the glacier. From these data, and other features exhibited by the mineral deposits, it is believed that the core of the mountain is granitic material related to the small bodies, and that all are of Tertiary age.

MINERAL DEPOSITS.

Types.—There are at least one hundred known mineral deposits on Hudson Bay Mountain that contain one or more of the following metals in important quantities: gold, silver, lead, zinc and copper. The mineral deposits occur mainly in four areas: the southwestern slope, Glacier Gulch, Toboggan Creek, and Simpson Creek. There are considerable differences in the nature of the mineralization; deposits are largely chalcopyrite and pyrrhotite, or

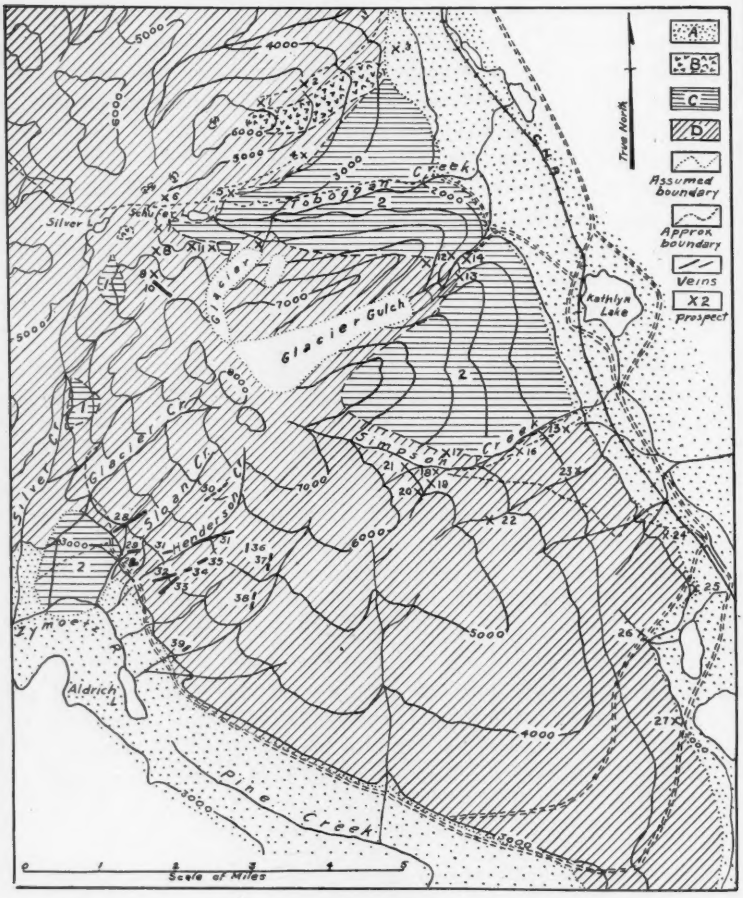


FIG. 2. Hudson Bay Mountain. Sketch map showing approximate location of mineral deposits. Canada Geological Survey, Dept. of Mines, June, 1936. *Northern Peak:* 1 Rico Aspen, 2 Evelyn, 3 Trixie, 4 Mt. Evelyn. *Toboggan Creek:* 5 Rio Grande, 6 Last Chance, 7 Iron Mask—Mammoth, 8 Iron Vault, 9 Silver Lake (White Heather), 10 Silver Lake —Trade Dollar, 11 Josie. *Glacier Gulch:* 12 Glacier Gulch (North Side), 13 Glacier Gulch (South Side), 14 Lake Kathlyn. *Simpson Creek:*

arsenopyrite with high gold values, or galena with some silver, or sphalerite, or tetrahedrite, or bornite. The last two carry high silver values. Many deposits exhibit the different types of mineralization in different sections and many show different types in the same sections. In all four sections, practically all types of mineralization have been found and two or more of the various types are closely related in many places. All deposits, including some scattered on the southeastern slope and on the peak north of Toboggan Creek, are therefore considered to be related, except a tetradymite-gold deposit in Glacier Gulch which is distinctly different from all others. Many other characteristics of the deposits indicate close relationships.

Distribution.—The distribution of the various types of mineralization is not systematic. Silver-lead (low temperature) deposits occur at all elevations from the lowest to the highest (Duthie to Silver Lake) and pyrrhotite-chalcopyrite and arsenopyrite-gold (high temperature) deposits occur in a similar range (from the Lake Kathlyn coal mine to the Iron King). On the southwest slope of the mountain, a high gold content occurs in deposits from near the base of the mountain on the Coronado property to near the top on the Mamie property but is absent in nearby veins that occur in the same range. Silver and lead are abundant near the base of the mountain on the Henderson and Coronado properties, and in mining to a depth of 600 feet on the former property no marked change was noted in the character of the ore. Galena occurs in the Victory, Mayflower, Canary, and Neepawa deposits, in places in fair amounts, at elevations well above the Mamie, where none is reported throughout a very con-

15 Vancouver, 16 Cascade, 17 Yukon, 18 Jessie, 19 Empire, 20 Dorothy, 21 Heather, 22 Snowshoe, 23 Lone Star. *Southeastern Slope:* 24 Zobnic, 25 Zeolitic, 26 Smiters, 27 Canadian Citizen. *Southwestern Slope:* 28 Victory, 29 Coronado, 30 Iron King, 31 Mamie, 32 Duthie (Ashman), 33 Duthie (Henderson), 34 Duthie (Humming Bird), 35 Duthie (Canary), 36 Mayflower, 37 Neepawa, 38 Neepawa, 39 King Tut.

A, alluvium and glacial drift; B, diorite and grandiorite; C, well-bedded rocks, mainly sediments—1, middle Jurassic, 2, lower Cretaceous; D, poorly bedded rocks, mainly volcanics.

siderable range up the slope. In Glacier Gulch, high temperature pyrrhotite-chalcopyrite mineralization occurs in the Lake Kathlyn coal mine, in the Skeena formation, at a point that is probably farther from the core of the mountain than any of the other deposits in this area. Many of these deposits carry low temperature silver-lead mineralization. One vein can be traced down a nearly vertical slope for several hundred feet and shows no change in this direction toward a higher temperature type of mineralization. It is clear that zonal arrangement of the various types of mineralization, from low temperature to high temperature toward the core of the mountain with change in depth, is not an important factor in their distribution.

Character.—The deposits in places are distinctly sheared parallel to their strike. On the Silver Creek property high temperature pyrrhotite-sphalerite mineralization is crossed by low temperature silver lead mineralization.[2] Elsewhere veins of one type of mineralization cut across veins of another type and follow shearing that has effected the early type and not the later. Most of the deposits are banded and commonly several bands have been formed by deposition upon both walls of an open fracture, thus indicating re-opening of fractures after filling by each band or group of bands. Thus it is evident that there were movements in the rock during mineralization and that the mineralizing solutions travelled different courses and were different in composition at different times. It is believed that this factor was largely responsible for differences in the character of mineralization from place to place.

Relation to Skeena formation.—In general the deposits are found on the outer slopes of the mountain, that is, on spurs rather than in valleys or cirques. In Glacier Gulch only one low-grade deposit was found in the bottom of the valley even where glaciated surfaces yield unsurpassed exposures. On the upper walls of the cirque and also on the lower walls toward the east, away from the core of the mountain, numerous deposits have been found. They lie in a narrow zone mainly a few hundred feet wide immediately

[2] Jones, R. H. B.: Hudson Bay Mountain. Can. Geol. Surv., Sum. Rept. pt. A p. 120, 1925.

below the shell of the Skeena formation. This whole zone on either side of the valley is clearly visible and the rocks within it are much more rusty than those above or below. Although the Skeena formation rests unconformably on the older rocks there is no evidence that the rustiness is due to an old weathered surface. The general rustiness of the zone in which the deposits occur is probably due to a certain amount of general mineralization.

In Toboggan valley, cirques on the south side cut deeply in toward the core of the mountain. In the bottoms of the cirques and on the lower walls toward the core, no mineral deposits are known to occur. They are abundant on the tops of the walls, and on the nearby spurs. Near the outer limit of the cirques, deposits can be seen clearly to pinch out downward. On the southwestern slope of the mountain the workable part of the Duthie or Henderson vein was found to be shorter on successively lower levels, and no workings were more than 600 feet below the surface. On the Mamie vein an adit was driven at a depth of 150 feet to overlap 40 feet of the better part of the vein exposed on the surface and in an upper adit. The vein was found to be much lower grade. Streams cut into the southwestern slope and intersect some of the veins which certainly are not better at these lower levels, but rather, are poorer. In general, all over the mountain the mineralization does not continue toward the core.

The four main areas of mineral deposits occur near or under the remnants of the Skeena formation. In all cases where they occur near it, a reasonable projection of the formation according to known dips and strikes and general attitude would carry it over the mineralized areas at no great height above the present surface. Away from the areas of the Skeena formation, where erosion might be expected to have cut deeper into the older complex, the deposits are few and tend to be lower grade. Some scattered deposits occur in the older complex near the base of the mountain, and these are possibly near remnants of the Skeena formation that are buried beneath valley gravels. Thus it appears that mineralization is confined largely to a zone that lay below the former extension of the Skeena formation.

Mineralization is rare in the Skeena formation. Pyrrhotite-chalcopyrite mineralization, however, was found in the Lake Kathlyn coal mine. Pyrite and chalcopyrite occur in it on the Rio Grande property on Toboggan Creek. On the Victory property on the southwestern slope, 150 feet below the lowest adit and on the strike of the main vein, a similar vein but with the sulphides removed by oxidation continues in the Skeena formation. Other similar veins also occur. On the peak north of Hudson Bay Mountain, deposits occur in the volcanic series classed as Upper Cretaceous. There seems to be no doubt that the mineralization is younger than the Skeena rocks but that in the main it did not penetrate them to any important extent.

Structural Features.—The deposits occur in a variety of fractures and under different structural conditions. A few occur along the bedding and in shear zones on anticlines (Homestake deposit and others nearby), in shear zones in granodiorite (Silver Creek), and as replacements in limestone (Silver Creek). Some mineralization occurs along bedding in sediments and it may occur along unconformities (Rio Grande). In the Duthie mine one vein is reported to occupy a fault. Elsewhere other types may occur but in the main the deposits occupy fractures that appear to be related to the domal structure of the mountain.

The most important deposits are fairly straight, long, fissure veins. Their lengths range up to 3,700 feet and workable lengths have been demonstrated for 1,100 feet. Ore widths commonly range from 1 to 6 feet and in some deposits the total altered zone is much greater. Much of the vein material has been deposited in open spaces. These deposits occupy fractures or sheeted zones that strike mainly toward the peak of the mountain and dip from 45 degrees to vertical. A few veins south of Toboggan Creek trend at right angles to this direction, but here the structure of the Skeena strata indicates a local cross fold. The fracturing in the surface part of each sheeted zone is best developed in the central part. Here also the deposits are widest and show the maximum open space deposition. Away from the central part on the surface, and at depth, the zones either have fewer and less well defined fractures, or the fractures are more scattered and the

deposits become poorer. The fractures are, therefore, believed to be due to tension. They remained open during mineralization and were periodically reopened. Rarely there is shearing along the zones, some of this was developed during or after mineralization. Deposits of this type include most of those on the southeastern slope, at least one in Glacier Gulch, several on the Silver Lake and Silver Creek properties on Toboggan Creek, probably most of those on Simpson Creek, and others scattered elsewhere.

Abundant small deposits occur in irregular fractures below the contact of the Skeena formation in Glacier Gulch and Toboggan Creek valleys. Many in the Glacier Gulch area strike parallel to the contact, but dip at different angles, mainly to the west, whereas the contact dips east. Several flat-lying fractures pass in places into a single, steeply-dipping fracture. They appear to owe their origin to the differential movement between the massive volcanic core and the overlying bedded Skeena formation.

Relation to Granitic Rocks.—It is believed that the granitic rock was intruded in the centre of Hudson Bay Mountain under great force and was responsible for the doming of the rocks, for many minor deformations, much fracturing and much induration and alteration. The sedimentary beds of the Skeena formation, because they originally were in relatively flat layers, adjusted themselves fairly readily by sliding layer on layer, but the irregular, largely massive and badly deformed complex below was subjected to great and irregular strains and adjustments and was to a considerable extent fractured and sheared. The strains were naturally great at the contact with the Skeena formation, hence the intense fracturing there. The major radial fractures appear to be the result of the doming; the tension naturally would be greatest in the outer parts of the dome and would decrease inward. The rocks now exposed were probably comparatively close to the surface, so that innumerable small and irregular breaks formed rather than large ones and open fractures tended to remain open. Mineralization probably began after intrusion was largely complete and solidification of the granitic mass had set in as the main structures were largely complete, and some deposits occur in the granitic rocks. Later adjustments, probably

due mainly to subsidence upon solidification and cooling, exercised considerable control over the movement of mineralizing solutions by closing some channels and opening others.

Localization below the Skeena sediments is due in part to more intense fracturing there and in part to the sediments acting as a barrier to further progress outward of the mineralizing solutions. The thick argillites in the basal part of the series are not favorable for mineralization and were probably relatively impervious to the solutions. The domal structure would also naturally tend to cause the solutions to migrate upward along the base of the Skeena formation and in places return to the more hospitable volcanic rocks.

CANADA GEOLOGICAL SURVEY,
OTTAWA, CANADA,
May 7, 1937.

DISCUSSION AND COMMUNICATIONS

THE FLORIDA SHIP CANAL.

INTRODUCTION.

Sir:—The interesting article by Sidney Paige [1] in this JOURNAL on the much-publicized Florida ship canal deserves a few references by way of background for readers unfamiliar with the subject and principles involved. Omission of references possibly may be condoned by precedent in certain types of official or private reports intended only for practical use and limited circulation. But total lack of citations in a lengthy article on a complex and controversial subject in a scientific journal is most unusual.

In the first place it should be stated that the article is a condensation and revision of an official report already published,[2] which, however, had only limited circulation and restricted geological audience, so that its appearance after rewriting, in a geological journal seems appropriate. In the second place, although the several maps used as illustrations contain a notation referring to the U. S. Geological Survey and Florida Geological Survey as their source, the fact that they are identical, except for additions pertaining to the canal, with various plates in a recent U. S. Geological Survey publication [3] is not indicated, nor is the existence of this report nor its author's name mentioned. In the third place, the discussion of principles controlling the relations between salt and fresh ground-water is presented, unfortunately,

[1] Paige, Sidney: Effect of a sea-level canal on the ground-water level of Florida. ECON. GEOL., vol. 31, pp. 537–570, 1936.

[2] Interim Report of the Special Board of Engineers, U. S. Army Corps of Engineers, entitled "Geological and ground-water conditions in Florida in their relation to the Atlantic-Gulf Ship Canal." Published as Senate Document No. 147, 74th Congress, 2d Session, 1936.

[3] Stringfield, V. T.: Artesian water in the Florida Peninsula. U. S. Geol. Surv. W.-S. Paper 773–C, 1936.

without reference to its history. Although the fundamental principle has sometimes been referred to as the "theory of Herzberg"[4] since 1901 and was discovered by the Dutch even earlier, so that it has been current for a considerable time, it is of such specialized application that relatively few geologists and scarcely any lay-men have heard of it. Readers might mistakenly conclude from Mr. Paige's paper that he and his associates had discovered and developed these principles. The first important application of these principles in the United States was in the work of the New York Board of Water Supply on Long Island.[5] The history of the subject is conveniently summarized in papers by the writer,[6] and the principles outlined have been expanded and refined in later studies, particularly by the State of New Jersey,[7] and the Honolulu Water Commission.

DISCUSSION.

Ground-water Gradients.—Proceeding to the substance of the article, it contains a good deal of argument that seems open to debate and perhaps dissent. In Fig. 11 Mr. Paige presents a series of profiles of the water table based, evidently, on the map of the piezometric surface as shown in Fig. 8. The object is to show that steep water table gradients are characteristic of the area where the canal will cut the Ocala limestone and that, therefore, the canal cut will lower the water level appreciably only in a very narrow notch near the canal. "This conclusion is based on the study indicated above of hydraulic gradients observable to-day within the outcrop area of the Ocala limestone coupled with the fact that the artificial canal-cut will traverse an area wherein re-

[4] Herzberg, Baurat: Die Wasserversorgung einiger Nordseebäder. Jour. Gasbeleuchtung und Wasserversorgung, Jahrg. 14, München, 1901.

[5] Spear, W. E.: Long Island sources of an additional supply of water for the City of New York, vol. 1, New York Board of Water Supply, 1912.

[6] Brown, J. S.: Relation of sea water to ground-water along coasts. Am. Jour. Sci., 5th Ser., vol. 4, pp. 274–294, 1922. Also, A study of coastal ground-water with special reference to Connecticut. U. S. Geol. Surv. W.-S. Paper 537, 1925.

[7] See for example, Barksdale, H. C., and others: Supplementary report on the ground-water supplies of the Atlantic City region. State Water Policy Commission of N. J., Special Rept. 6, 1936.

sistance to flow (of) water through the rocks will be substantially higher than in areas wherein underground drainage gradients have been during a long period reduced to graded slopes." (p. 568.)

As a matter of fact it is questionable whether all, or possibly any, of the gradients pictured can be said truly to represent gradients normal to the area of surface exposure of the Ocala limestone. Referring to the geological map of Florida by Cooke and Mossom [8] it appears that profile *A*, Fig. 11, barely touches the area of Ocala outcrop, but traverses mainly Hawthorne and later formations parallel to the margin of Ocala outcrop. Profile *B* is on Hawthorne formation and Tampa limestones. Profile *C* is perhaps admissible although its steepness might suggest field explanations not obvious on the map. Profile *D* is chiefly on Glendon and Tampa limestones, above the Ocala. Profile *E* is entirely across Hawthorne and later formations. Of profiles *F* and *G*, more later.

Comparison of the piezometric map with the geological map and with available contour maps shows that the piezometric highs to which Mr. Paige devotes much space, correspond not entirely to topographic highs but to the conjunction of topographic highs with areas of less freely, or less coarsely, permeable rocks, in part the Hawthorne formation, and in part later and less consolidated materials of residual, fluvial, or littoral origin and Pliocene age. These rocks evidently retain water relatively tenaciously and favor steep water table gradients, as Mr. Paige clearly distinguishes (p. 556).

Further comparison of the geological, piezometric and topographic maps, shows that the general area of Ocala outcrop, roughly shown in Fig. 3, is divisible into two sections piezometrically, by a line drawn through Dunellon slightly west of north and east of south. To the east the water table in the Ocala formation is quite flat; to the west it slopes off, at first rather steeply, then more gently, to the sea. This line of division corresponds in a general way with a well-defined topographic

[8] Cooke, C. W., and Mossom, Stuart: Geology of Florida. Fla. Geol. Surv., 20th Ann. Rept., 1929.

ridge that is bisected at Dunellon by the Withlacoochee River. On the geological map it corresponds, also, with an area mapped as Alachua formation and described as residual material derived from Hawthorne and younger rocks. The Alachua is well-known, otherwise, as the source of the extensive Florida hard-rock phosphates. It is not, therefore, fairly representative of genuine Ocala outcrop, even though so shown on a generalized geological map. Indeed, it seems a fair inference that these materials, like others overlying the Ocala, are less permeable. They tend to produce piezometric highs but in this instance fail, and so succeed only in acting as an imperfect dam to the ground-water escaping westward. It is certain that the Alachua extends downward very unevenly into the underlying Ocala, and at places probably blocks some of the subterranean passages into which it has slumped. For obscure reasons the dam is more effective north of Dunellon than to the south and so produces a local slight offset in the general dividing line as previously defined, the offset corresponding closely to the course of the river at Dunellon.

Profiles *F* and *G* represent particularly steep portions of the break in ground water gradient in the area of this Alachua residuum, further complicated by the presence of a power dam on the Withlacoochee. Incidentally, no drop of 25 ft. (profile *F*) to the Withlacoochee is shown on the piezometric map, although possibly it may have been substantiated by local data. Instead a drop of about 10 or 15 feet is indicated southward to the river, and, if Mr. Paige had chosen to continue his profile south, an additional 10 or 15 feet *away from the river,* indicating that in this section the river is losing water underground to the south and west.

Mr. Paige's gradients are here tabulated against others, which it would seem might apply equally as well or better.

The suggested gradients seem more reasonable than Mr. Paige's because (1) they cover the heart of the Ocala exposure in the region that may be affected by the canal, and (2) none of them represents short or freakish variations from normal gradients, such as D, F, and G.

PAIGE GRADIENTS.

	Miles	Ft. Drop	Ft. per Mile
A	78	135	1.7
B	22	85	3.9
C	13	50	3.9
D	5	30	6.0
E	38	80	2.1
F	2	25?	12.5
G	4	20	5.0
Total and average	132	325	2.5

OTHER SUGGESTED GRADIENTS.

	Location	Miles	Ft. Drop	Ft. per Mile
H	Gainesville west to county line	20	10	0.5
I	Continue H west to Suwanee R.	20	35	1.75
J	Ocala S.W. to Withlacoochee R.	20	15	.75
K	Tsala, Apopka Lakes west to Crystal Bay	23	30	1.30
L	Croom, on Withlacoochee, N.W. to Crystal Bay (Profile E extended over actual Ocala outcrop)	40	40	1.00
	Total and average	123	130	1.05

It should be noted that in deducing his hypothetical gradient near the canal (indicated on profile *A*) Mr. Paige uses not even his average gradient of 2.5 ft. but an approximation of his steeper grades amounting to 40 ft. in 10 miles or 4 ft. per mile! It would seem to the writer that an average between one and two ft. per mile would accord much better with the probabilities. The justification of the steep gradient assumed by Mr. Paige is given as topography coupled with the supposed tendency of underground flow to adhere to existing gradients of the present water table. It is implied that the canal will be a deep, narrow cut with steep slopes, and steep ground-water slopes resembling those north

of the Withlacoochee at Dunellon will result. How do the steep slopes to the south, *away from the river and against opposing topography,* at Dunellon, fit into this assumption? Evidently the true control is local permeability and not topography. Mr. Paige has admitted this in another section (p. 554) where he states: "Movement of water within the uppermost part of the Ocala limestone is decidedly free, and it is largely due to this fact that the water table is so flat over much of the terrain underlain by the Ocala limestone."

The Ocala limestone is notoriously honeycombed by solution caverns of all sizes, and it is well-known that cavities of large size are numerous at depths even well below sea-level. This condition has been described as follows:[9]

> The development and enlargement of subterranean channels within the porous Ocala and Tampa limestones has been proceeding for geological periods and the capacity of such drainage systems is to-day enormous. Aside from numerous passages developed at considerable depths below the water table such as those discharging under artesian head there exist many subterranean systems just below the water table but draining the land as truly as do surface streams.

It seems to me altogether likely that when the imperfect natural dam formed by the Alachua formation is breached at Dunellon and the subterranean passages to the east are opened by the canal the water table will assume its normal average flatness, rising from the canal at a rate considerably less than 40 feet in 10 miles. This applies of course only to the area of Ocala exposure. Gradients, presumably, would steepen markedly at the marginal contacts with less permeable cover.

Attention may well be directed again to the anomalies of the Withlacoochee River in relation to the piezometric map. From eastern Hernando County north through Tsala Apopka Lakes and west past Dunellon the piezometric slopes on the west (at Dunellon on the south) are away from the river in spite of high topographic barriers. Plainly all this area is losing water heavily by subterranean discharge to the west, a deduction confirmed by Stringfield[10] and by the occurrence of four of Florida's large

[9] Interim Rept. of the Special Board of Engineers, p. 2.

[10] *Op. cit.*, p. 153.

springs near the sea in western Citrus County.[11] The lakes and river are maintained only by heavy inflow from the east and northeast. This inflow is evidenced by the numerous tributary swamps and springs on that side and the lack of corresponding features on the west and southwest. Construction of the canal would inevitably intercept and divert practically all of this supply and conceivably might cause the river, in this section, to disappear.

The rather involved discussion of spillways by Mr. Paige impresses me as having little practical application to the problems set forth.

Contamination.—One important map in the Stringfield report was not used by Mr. Paige. It shows the extent of salt water contamination in the deeper aquifers, principally the Ocala limestone. Water containing 100 or more parts per million of chloride is classed as highly mineralized. (In a general way water containing about 300 parts per million of chloride due to sea water is noticeably salty to the taste.) For purposes of this discussion reference may be made to Fig. 3 of Mr. Paige's paper, since the area of contamination happens to be very similar to the area of artesian flow as there shown. All deep well water from Lake Okechobee south, and in a belt some 30 miles wide along the east coast, as far north as St. Augustine, contains from 100 to several hundred parts per million of chloride. On the west coast the area is restricted, even smaller than the narrow fringe of artesian flow.

Various causes probably contribute to this contamination. Stringfield[12] attributes it mainly to the imperfect flushing of the original or connate sea water that, presumably, filled these marine formations before the land was elevated above sea-level, but suggests that in some degree it may come from actual salt beds in the strata. The Interim Report of the Special Board of Engineers,[13] ascribes salinity in the Lake George area to bottom-water salting, that is admixture of salt water from the prevailing underlying basement of sea-water, and dismisses it as unimportant.

[11] *Op. cit.*, pl. 15, opp. p. 156.
[12] *Op. cit.*, pp. 162–164.
[13] *Op. cit.*, pp. 29–30.

"Salt water encroachment from the bottom of the ground-water reservoir upward to the St. Johns River in the Lake George region is not now greater than 1 per cent. of the total flow of the river."

This statement is true enough when the small volume of naturally escaping salt water is diluted with a large volume of surface flow, but by no means true of wells or springs. One of the principal sources of salt is Salt Spring, near Kerr Lake in the Lake George area, eastern Marion Co., only 20 miles from Ocala. Salinity there is reported as 2662 parts per million of chloride, or roughly 15 per cent. contamination if most of this is due to sea water.[14] This certainly would be important in a well. Concentrated sea water, theoretically, should be present in much of the Lake George-St. Johns River area within a few hundred feet of the surface, as the piezometric head is only 10 to 20 feet above sea-level.

Cutting of the canal cannot but lower the hydraulic pressure to some degree along the Oklawaha-St. Johns drainage, even if only slightly, and slight changes in an area already seriously contaminated could cause great local increases in contamination and might considerably enlarge its area.[15] A good deal probably will depend on how far east the canal may uncover the buried Ocala limestone. The Interim Report of the Special Board of Engineers (p. 24) states that near Silver Springs the Ocala

[14] Meinzer, O. E.: Large springs in the United States. U. S. Geol. Surv. W.-S. Paper 557, p. 10, 1927.

[15] The following explanation of some features of the distribution of salinity seems worthy of consideration. In an artesian system like that of Florida which, for the most part, probably has no very free subterranean outlet, areas elevated above sea-level would be flushed of their connate water quite slowly. However, once flushed, if they should be resubmerged, salt water would reoccupy its proper position only very slowly. The coast at Jacksonville shows evidence in the depth and nature of the St. Johns River of recent drowning on the order of 50 to 100 feet. The absence of any saline zone in this region perhaps indicates former flushing somewhat farther seaward. Southern Florida, on the other hand, shows evidence of recent emergence and perhaps has not had time for effective flushing of its artesian system. The differential tilting between the two areas may very well cause considerable migration of saline waters from the south toward the north and so account for a good deal of the wide zone of contamination around Lake George, where salt springs and wells are common and salinity is quite erratic. The erratic nature of the salinity might seem to imply some condition of maladjustment, for ordinarily the salt water-fresh water contact is apt to be well defined in stable areas.

" plunges off steeply in a buried, erosional escarpment to nearly 30 feet below sea-level." . . .

Yet, if the Ocala is only *nearly* 30 feet below sea-level and the canal is to be 30 feet below, the hazard of cutting Ocala at places seems considerable, and in fact Mr. Paige in Fig. 10, ECONOMIC GEOLOGY, shows the canal cutting Ocala 20 miles northeast of Silver Springs.

Perhaps more important than possible increases in the existing area of salinity is the probable rise of salt water from below in the region of Ocala outcrop due to lowering of the water level. This is the feature Mr. Paige has minimized so strongly by the use of suggested profiles as already discussed. If, as seems to me more reasonable, the drawdown near the canal produces a gradient somewhere between one and two feet per mile, the water level over an area some 20 to 40 miles wide near the canal will be reduced to only a few feet above sea-level, similar to the present head in the Lake George area, and salt water may be expected to rise, sooner or later, to a point where it will affect wells in the Ocala formation at no great depth. This might happen to the Ocala water wells at a depth of 225 feet, although it is probable that a supply of fresh water adequate for present needs could still be obtained by reducing the depth of the wells.

Just how fast salt water from below would rise to establish equilibrium after the water table had been lowered probably is a matter of conjecture. Mr. Paige seems to imply that the 1900 feet of fresh water now theoretically present below Ocala might resist displacement for a substantial period, and perhaps it might. However, one other aspect of contamination would seem to enter at this point, one briefly touched on in the Interim Report of the Special Board of Engineers (pp. 28–30) but not in ECONOMIC GEOLOGY. This is the effect of open salt water incursion along the canal at its western outlet. The eastern outlet it is assumed, with reason, will remain substantially unchanged, as the St. Johns River is already tidal and will not be deepened in its lower portion. The Interim Report describes salt water contamination in a tidal stream as caused by a " salt-water wedge " along the tidal channel. Fresh water discharges by flowing over the concentrated salt

water in the form of a sheet that grows thinner toward the outlet. Conversely, the salt-water wedge grows thinner inland and disappears at a point where the added head of fresh water is sufficient to maintain equilibrium with the salt, a principle much like that whereby fresh ground-water floats on salt water. For a 30-foot depth of salt water at the outlet the necessary head of fresh water above sea-level is about 0.78 ft. The salt-water wedge on the east is said to extend inland approximately 25 miles, to Ortega, above Jacksonville. Presumably a similar incursion of sea water would occur to some extent at the western end of the canal, probably extending at least to Dunellon, perhaps farther, in spite of suggested means of minimizing it.

Now in an ordinary tidal stream of wide channel like the St. Johns River, sedimentation usually builds a floor of fine and relatively impervious silt which is fairly effective as a seal to prevent active settling of the heavier salt water where fresh water is present below, and in addition the natural hydrostatic head toward the place of outlet assists this sealing effect. Nevertheless, experience shows that the water beneath tidal channels is commonly too salty for human use.

In the case of the proposed canal, the channel will be narrow, promoting swift currents that will inhibit silting, and will be cut in porous rock with no natural silt floor. Assuming that salt water from below does not rise immediately, will not the heavier salt water of the salt-water wedge tend to settle and contaminate the ground water to some degree for whatever distance it may extend eastward?

Conclusions.—In summary, it seems that the following effects of the proposed canal would be assured:

1. Some probable increase in the flow of the Oklawaha-St. Johns Rivers, although this would depend on just how the natural flow in the canal should divide itself.

2. Creation of a similarly large westward-flowing stream from the divide (location uncertain) westward.

3. Substantial lowering of the water table over a wide area in Citrus, Sumter and Western Marion counties, necessitating the deepening of shallow wells.

4. Substantial decreases in flow, conceivably even total disappearance, of such streams as:

a. Blue Springs Run.
b. Silver Springs outlet.
c. Withlacoochee River below Tsala Apopka Lakes. This would be accompanied by some lowering of level and decrease in area of those lakes, and adjacent swamps.

The proposed construction of mitigating structures (dams?) would be futile if there were little or no surface flow to impound.

5. At least slight lowering of the water table in parts of eastern Marion County, probably accompanied by some definite increase in the area of saline waters in that locality.

6. Upward incursion of sea water into the lower portion of the Ocala formation over the same area in which the water table might be substantially lowered.

With Mr. Paige's remarks regarding vegetation I am inclined to agree that the effects would not be serious. His statement that the canal would not affect the present city water supplies of Tampa, Palm Beach and Miami seems to me obvious. His similar conclusion respecting Jacksonville and Sanford probably is acceptable with only slight reservation as to the possibility of some increase in salinity in those areas. As a whole the report minimizes unduly the adverse features of the canal. On the other hand it seems to fail to take full advantage of emphasis on the possible beneficial effects in the drainage of swampy areas, which might be considerable.

The foregoing discussion doubtless will be criticised on the basis that I have not studied the matter on the ground. To this I would say that Florida is one of the numerous areas in which so much excellent groundwork is available in published reports that many of its problems are susceptible to a considerable degree of analysis from these alone. I believe I have confined myself to those features that are suited to this type of analysis by any person familiar with the principles involved.

JOHN S. BROWN.

EDWARDS, NEW YORK.

REVIEWS

The Magmatic Nickeliferous Ore Deposits of East Griqualand and Pondoland. By D. L. Scholtz. Pub. Univ. of Pretoria, Series II: Natural Sci. No. 1, Part I, pp. 91; pl. 16. 1936. (Reprinted from Trans. Geol. Soc. of S. Africa, vol. 39.)

This is a comprehensive paper on a series of interesting deposits and the microscopic features are exceptionally well illustrated by 102 photomicrographs. The paper includes a brief summary of previous literature on the area. The rocks of the area consist especially of Karoo sediments that attain a maximum thickness of 22,000 feet. Dolerite has been injected into the Karoo beds over an area of 200,000 square miles. Vast quantities of basalt were poured out of fissures and later extensively removed by erosion. The intrusives consist of dikes, sills and inclined sheets. Assimilation in the dolerite is believed to have been unimportant and stopping also was of little consequence. The volume of the dolerite is estimated to be between 50,000 and 100,000 cubic miles.

In the Mount Ayliff area there are four large masses of gabbro, which are probably sheets, varying from less than 1,000 to over 3,000 feet in thickness. These are all trough shaped with generally low dips, but attaining 40 degrees. The original intrusions consisted of a roof zone of granitic composition which grades imperceptibly into a central gabbro zone. The gabbro forms the main mountain masses. Olivine is abundant in the lower part of the central zone, grading into the basal zone, which is characterized by various types of peridotite, and carries the principal ores. A contact metamorphic aureole of hornfels varies from 200 to 400 feet in width. The petrography of the rocks is described in considerable detail, and there are chemical analyses and detailed optical data on important minerals.

The roof zones have an appreciably higher ore content than the central zone, but neither is expected to produce commercial ore. The basal zone contains local concentrations that show good values, but ore exposed at present is of irregular habit and of limited extent.

The mineragraphy of the ores is treated exhaustively in a 45-page section and is an excellent example of the value of careful microscopic studies of ores. The ore minerals are magnetite, ilmenite, spinel, pyrrhotite, pyrite, pentlandite, chalcopyrite, cubanite, bornite, chalcocite,

covellite, sperrylite, bravoite, marcasite, vallerite, galena, bismuth, gold, nicollite, blende, and millerite. In addition, sixteen rare minerals of uncertain identity are listed in a table.

Pyrrhotite is the principal sulphide, but the mineral is not simple as it shows an intergrowth of two components, which have resulted from ex-solution. The various textures and structures in the ores are completely illustrated by 84 photographs of polished ores. Small amounts of pentlandite probably also represent an ex-solution product. Pyrite replaces pyrrhotite along cracks and partings. Pentlandite is the most abundant nickel mineral and is found in practically all ores. It occurs as a massive primary type and as various intergrowths of secondary (not supergene) origin. Vallerite is developed in pentlandite but is not believed to be an ex-solution product. Bravoite belongs to a much later mineralization than pentlandite and is a common alteration product of it. Chalcopyrite is abundant and occurs in two generations, the first being later than pyrrhotite. The order of crystallization of the principal sulphides is given as pyrrhotite, pentlandite, chalcopyrite.

Cubanite occurs as abundant ex-solution intergrowths with chalcopyrite also as nearly pure masses. Cubanite is thus contemporaneous, at least in part, with chalcopyrite. Vallerite also tends to occur in chalcopyrite especially along its contact with other minerals.

Millerite is thought to be later than pentlandite and chalcopyrite, but earlier than bravoite. Bornite and chalcocite are in general later in origin, but show very complex relationships.

Unfortunately the author does not summarize the order of formation of the extensive series of minerals. A diagram of the probable paragenesis of this unusually complex series of ore minerals would aid materially.

Regarding the origin of sheet-like ore masses near the lower contact, Scholtz says:

> All available evidence points to the fact that the sulphides of the latter type filled fractures which developed near the basal contact shortly after consolidation of the chill phases and olivine-hyperite at relatively high temperatures, and there can be no doubt that, in spite of the transgressive habit, these sulphides are closely related to those of the former type, (Disseminations in olivine hyperite).
>
> The ore which separated from the magma was concentrated in the basal zone by gravitational differentiation to form pools within hollows and irregularities present in the floor of the intrusion. Droplets of late arrival were unable to penetrate the viscous lower portion of the olivine hyperite, and the ore thus held by the cooling rock filled the spaces between the mush of crystalline matter, which eventually consolidated to form the mineralized olivine hyperite.

The activity of hydrothermal solutions following the magmatic origin is also discussed and this phase is considered a different stage of the broad process of magmatic differentiation.

The paper is an important contribution to ores of the Sudbury type and because of the detailed work on many intergrowths of ore minerals should be available for reference in any laboratory where microscopic research on ores is carried on.

G. M. SCHWARTZ.

Coal its Constitution and Uses. By W. A. BONE AND G. W. HIMUS. Pp. xvi + 631, figs. 134, pl. 9. Longmans, Green & Co., London, New York and Toronto, 1936. Cloth 10 × 6½. Price, $7.50.

This book is a comprehensive study of coal especially with reference to its composition and its technical aspects. In its introduction it calls special attention to the fact that emphasis is placed on conditions as they exist in Great Britain and the British Empire. It purports to review the results of recent researches on the chemical constitution and geological history of the different types of coal and coaly materials as well as the classification and geographical distribution of the world's available coal resources and their economic aspects.

The most impressive portions of the volume are the chapters on the geographic distribution of coals within the British Empire and those on the technology of coal, such as the proper use of coal and coal-oil mixtures, its use in the carbonization industries, its complete gasification, its most efficient use in the manufacture of iron and steel, its hydrogenation, etc. These chapters are well provided with charts and graphs and sectional sketches of boilers, retorts, etc., and are enlivened by many historical references.

The chapter on the origin, formation and classification of coals is too brief to be satisfactory to American students. There is no reference to Parr, Cady, Thiessin or White in the bibliography appended to the chapter.

The three chapters on the chemical composition of coal deal with the subject under three heads: (1) the thermal composition of the coal substance; (2) the extraction of coals with solvents; and (3) the benzenoid structure of coals. Each of these topics is discussed briefly, though satisfactorily, if one does not insist that some attention should be given to the work of American coal students during the past decade.

The book contains an immense amount of valuable information on coal in general and gives an excellent summary of the work that has been done on the subject in Great Britain and the Empire. It is a good reference book to have on one's shelves.

W. S. BAYLEY.

The Geology of South-Western Ecuador. By GEORGE SHEPPARD (with a chapter on Foraminifera by T. W. VAUGHN). Pp. 275; figs. 195. Thos. Murby, London, 1937. Price 25/-.

This volume by Dr. Sheppard, State Geologist of Ecuador, is the first comprehensive treatise on the geology of this little known country. The chapters deal with climate and physiography, sedimentation of the Tertiary formations, stratigraphic geology, Tertiary foraminifera (by T. W. Vaughan), structural geology, cherts and igneous rocks and petroleum. There is a valuable bibliography, and the book is well illustrated by many good photographs and line drawings. A number of photomicrographs and camera lucida drawings indicate the carefulness of the petrology. The section on stratigraphy, with drawings of fossils, is particularly valuable. The occurrence and distribution of petroleum is given and the character of the oils is shown. It occurs in sands ranging from upper Eocene to Oligocene in age and is found at depths of from 850 to 3500 feet.

The book is authoritative, carefully written, and nicely printed, and is the best pertaining to this region. It should be a boon to those interested in petroleum in Ecuador.

ALAN BATEMAN.

Vulkane und ihre Tatigkeit. By A. RITTMAN. Pp. vii + 188, figs. 25, pl. Ferdinand Enke Verlag, Stuttgart, 1936. Price, paper, 7.20 R.M.

In view of the fact that over 500 volcanoes are known to have been active within historical times and over 10,000 have left evidence that they have contributed to the building up of the Earth's crust as it now exists, the author feels that the importance of the study of vulcanology to the geologist has not been exaggerated. He, therefore, regards it advisable to discuss in a systematic and critical manner the subject of volcanoes, their products, their causes and the mechanism that has given rise to them. This he has attempted to do here under 6 heads—volcanic activity of all types, and its immediate products, the forms and structure of volcanoes and volcanic products, the physical-chemical characteristics of magmas and the mechanism of eruptions, the systematic development of volcanoes and their classification, the distribution of volcanoes in place and time and, finally, theoretical considerations.

There is nothing essentially new in the book, but the assimilation of the upper portion of the crust by rising basic magma is emphasized as the explanation of the variation in the nature of lavas—from basic, through intermediate to acid types—and the change from quiet to explosive activity.

The author surmises that there cannot be any satisfactory theory of vulcanology formulated that is not directly connected in some way with the oscillation theory of Haarmann.

The little book is an excellent summary of our present knowledge of volcanoes and of volcanic action, in spite of its failure to suggest a cause of the phenomena described.

W. S. BAYLEY.

Boletin de Geologia y Mineria. Vol. I, No. 1, 1937. Ministerio de Fomento, Caracas, Venezuela.

This is the first issue of a new government journal devoted to geology and mining in Venezuela, printed in Spanish.

Its purpose is to give an outlet to geological information and thereby to help in making known and developing the mineral resources of Venezuela. This first number consists of 90 pages, 19 figures, and 11 inset maps and charts. It is well printed on good paper. It contains 4 articles and a section on geological notices. The articles deal with the asbestos deposits of Tinaquillo; Tertiary gasteropods; gold production; and some coal occurrences. The journal will make available geological information previously inaccessible.

BOOKS RECEIVED.

J. D. BATEMAN.

Mineral Deposits of the Ruby-Kuskokwim Region, Alaska. J. B. MERTIE, JR. Pp. 140, pls. 6, index map. U. S. Geol. Surv., Bull. 864–C, 1936. Price, 25 cts. Placer and lode gold, silver-lead and cinnabar.

Ground-water Resources of Kleberg County, Texas. P. LIVINGSTON AND T. W. BRIDGES. Pp. 35, pls. 5, map. U. S. Geol. Surv., W–S. P. 773–D, 1936. Price, 10 cts.

Artesian Water in the Florida Peninsula. V. T. STRINGFIELD. Pp. 80, figs. 9, pls. 11. U. S. Geol. Surv., W–S. P. 773–C, 1936. Price, 20 cts.

Stratigraphic Classification of the Pennsylvanian Rocks of Kansas. R. C. MOORE. Pp. 256, figs. 12. Geol. Surv. of Kansas, Bull. 22, 1935. Conclusion that Pennsylvanian beds in North America should be defined to include the strata between the Devonian and Permian systems.

The Tertiary Floras of Alaska. A. HOLLICK. Pp. 185, pls. 121, map. U. S. Geol. Surv., P–P. 182, 1936, Price, $1.00. Hundreds of splendid floral photographs.

Cyanidation and Concentration of Gold and Silver Ores. JOHN VAN NOSTRAND DORR. Pp. 485, figs. 135. McGraw-Hill, New York, 1936.

Price $5.00. A record of the author's rich experience in ore treatment, and of modern gold and silver milling in the chief mining camps of the world. A necessity to the mill man, valuable to the miner, and should be read by the economic geologist.

Bibliography of the Geology of Newfoundland, 1818–1936. RACHEL M. BETTS. Pp. 35. Dept. of Nat. Res., Geol. Sect., Bull. 5, St. John's, 1936. Princeton University Contribution to the Geology of Newfoundland—No. 14.

Geology of Gold Deposits of Newfoundland. A. K. SNELGROVE. Pp. 46, figs. 13. Dept. of Nat. Res., Geol. Sect., Bull. 2, St. John's, 1935. General geological relations; descriptions of gold areas and prospects.

Chinese Fuels: Analysis, Approximation of Calorific Value by Heat Index, by K. Y. KING AND W. C. HSIA; Coking Properties of Tatung Coal, Modification of Pieters Methods for Prediction of Coking Properties, by K. Y. KING AND S. Y. HSIUNG; Report of Gas Plant of Geological Survey, by C. H. YOUNG. Geol. Surv. China Bull. 28, Nos. 18–21, 1936.

Contribuicões Para a Geologia do Petroleo no Reconcavo (Bahia). S. FRO'ES ABREU, GLYCON DE PAIVA, AND IRNAK DO AMARAL. Pp. 214, pls. 13. Rio De Janeiro, 1936.

La Industria Minera en al Perú, 1935. J. HOHAGEN. Pp. 401, figs. 12. Bol. del Cuerpo De Ing. De Minas Del Peru, No. 117, Lima, 1936. General progress report.

Relatório dos Trabalhos Executados Pelo Serviço de Aguas. A. J. ALVES DE SOUZA. Pp. 144, map. Dept. Nac. Da Prod. Mineral, Rio De Janeiro, 1936.

Energia Hydraulica no Brasil. A. J. ALVES DE SOUZA. Pp. 16, map. Serviço De Aguas, Dept. Nac. Da Prod. Mineral, Avulso N. 1, Rio De Janeiro, 1936.

Ground-Water Resources of the Shenandoah Valley, Virginia. R. C. CADY. Pp. 136, figs. 2, pls. 3, maps 2. Virginia Geol. Surv., Bull. 45, 1936. Pre-Cambrian to Pleistocene.

Deep-well Records, West Virginia. R. C. TUCKER. Pp. 550, plate, maps 2. West Va. Geol. Surv., 1936. Total depth of one hole, deepest in U. S., exceeds 9,000 feet. Other deep holes at 7,386 and 7,579 feet.

Upper Copper and Tanana Rivers, Alaska. F. H. MOFFIT. Pp. 8, map. U. S. Geol. Surv., Bull. 868–C, 1936. Price, 10 cts. Placer gold deposits.

SCIENTIFIC NOTES AND NEWS

F. Blondel has been elected President of the Geological Society of France.

Wallace E. Pratt on June 1 was elected a director of the Standard Oil Co. of New Jersey and was also made a regular member of the Executive Committee. Prior to his election to the board of the Standard Oil Co. of New Jersey, he was vice-president of the Humble Oil & Refining Company.

H. A. Brouwer of Amsterdam University, Holland, will lead a geological expedition starting the middle of June to the Lesser Sunda islands in the East Indies, particularly to the islands Alor, Wettar, Rotti, and Timor.

Roswell W. Prouty, mining engineer and geologist, is returning to Glendale, Calif., from Honduras.

J. G. Baragwanath, president of Pardners Mines Corp. of New York, has been made a member of the board of Dome Mines, Ltd.

P. G. Dobson, mining engineer and geologist of Bralorne Mines Ltd. of Vancouver, has been directing operations at the Nivloc mine near Silverpeak, Nev., in which Bralorne officials are interested.

E. C. Congdon, of Duluth, is president, and D. C. Sharpstone, consulting geologist of the recently incorporated Polaris-Taku Mining Co., Ltd., which will operate a gold mine in the Taku River section of northwestern British Columbia.

W. P. Alderson has returned to his headquarters in Montreal after a considerable stay in Kenya Colony, where he has started a mill on a gold property.

Francis G. Wells of the U. S. Geological Survey returned, in the middle of July, from a trip to Cambridge, England.

Victor M. Lopez, formerly geologist with the Chile Copper Co., at Chuquicamata, Chile, is now with the Ministerio de Fomento, Caracas, Venezuela.

Bailey Willis, as guest geologist to the Bureau of Science and Mines in the Philippine Islands, is making a reconnaissance of northern Luzon.

ERRATA.

Vol. XXXII, No. 4, p. 417, entire plate should be rotated 180 degrees, so that the figure labelled 33 becomes 25, 32 becomes 26, etc.

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